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OCCUPANT SURVIVABILITY IN LATERAL COLLISIONS VOLUME I

Contract No. DOT-HS-4-00922

January 1976

Final Report

PREPARED FOR:

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NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

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16. Abstract

The objective of this study was to investigate the feasibility of modifications to the interior and glazing of a full-size automobile which, when combined with structural modifications to upgrade structural integrity, would enhance occupant survivability in severe lateral collision accidents. Main elements of the project were (1) performance of baseline lateral collision tests under various impact modes, (2) developmental testing of advanced interior padding and glazing materials, (3) fabrication of vehicles incorporating modified structures, interiors and side glazing, (4) performance of lateral collision tests of the modified vehicles, and (5) evaluating the results and providing conclusions and recommendations relative to improving lateral impact protection

Results of this study indicate that the greatest deficiency of conventional automobiles relative to lateral impact protection is the general lack of energy-absorbing interior side surfaces Installation of crushable inner door panels and yielding padding materials in other sidewall areas demonstrated a significant improvement in occupant survivability under the lateral impact conditions considered Structural modifications alone are shown to be generally beneficial but appear to be fundamentally limited as to the extent of increased occupant protection that could be gained without associated improvement of interior sidewall energy absorption capability Peripherally supported, laminated side glazing was found to adequately provide an energy-absorbing containment surface However, anthropomorphic dummy response under the particular lateral impact test conditions investigated did not conclusively demonstrate a need for such a departure from conventional monolithic tempered glass, the viability of reverting to laminated side glass was also found to be questionable

Finally, recommendations are made regarding the need for (1) investigation of the effect of front structure collapse characteristics on the potential improvement in intervehicular lateral impact protection offered by side structure and/or interior modifications, (2) determination of the acceptability of anthropomorphic dummy lateral response fidelity, and (3) development of a suitable mathematical model to aid further investigation of the relative importance of structural and interior modifications in improving occupant survivability in lateral collisions

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FOREWORD

This report presents the results of a 16 month program entitled "Occupant Survivability in Lateral Collisions" performed by Calspan Corporation for the National Highway Traffic Safety Administration under Contract No. DOT-HS-4-00922. The program focused on evaluating the extent of occupant protection offered by a conventional, full-size automobile when involved in various types of intervehicular lateral collisions, and assessing the feasibility of improving such protection by the incorporation of structural, glazing and interior modifications (or combinations thereof). A total of seven baseline and six modified vehicle crash tests were performed, as well as a large number of developmental tests of various energy-absorbing glazing and padding constructions. The report is divided into two parts; Volume I is the main body of the technical presentation and Volume II contains supporting test data and related information

The Contract Technical Manager was Mr. Richard M. Morgan of the National Highway Traffic Safety Administration.

The opinions and findings expressed in this report are those of the author and not necessarily those of the National Highway Traffic Safety Administration.

This report has been reviewed and is approved by:

Edwin A. Kidd

Edwin A. Kidd, Head
Transportation Safety Department

ACKNOWLEDGMENTS

This report reflects the combined effort of many persons at Calspan Corporation. The author is particularly indebted to the Experimental Test Section of the Transportation Safety Department, Calspan's Facilities Machine Shop, and the Technical Services Department. Special thanks go to Drs. Edwin A. Kidd and Patrick M Miller, who provided technical supervision and guidance, Mr Kenneth N. Naab, who was exensively involved in the experimental testing effort, and Miss Alesia E. Kudela for her secretarial assistance.

The author also wishes to acknowledge important technical contributions to the automotive glazing investigation made by Mr Frank D. Lovett, Jr. of PPG Industries, Inc., and Mr Richard I. Morrison of Ford Motor Company PPG Industries generously provided the specially fabricated glazing test specimens

The author is appreciative of the enthusiastic and highly professional manner in which Mr Richard M. Morgan, NHTSA, carried out his responsibilities as Contract Technical Manager

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1. INTRODUCTION

The purpose of this study was "to investigate the feasibility of modifications to the vehicle interior and glazing which, when combined with structural modifications to upgrade compartment integrity, will allow occupants to survive severe accidents in (lateral collision) modes in a completely passive manner" (Statement of Work).

Structural modifications for lateral collision protection were developed in previous National Highway Traffic Safety Administration (NHTSA) research programs (Refs 1, 2 and 3). The modifications have clearly demonstrated improved structural integrity and energy management under severe fixed object and intervehicular lateral collision modes. Associated development of protective design features relating to the vehicle interior and glazing has also been previously undertaken (Refs. 2 and 3), but at a substantially lower level of effort This program was therefore intended to further investigate interior and glazing modifications for lateral protection to bring the state-of-the-art more in balance with the extensive structural crashworthiness research previously performed.

Interior and glazing modifications generally related to (a) providing crushable or deformable sidewall surfaces designed to limit and control lateral occupant loading and (b) providing side glazing that is more effective in containing occupants within the confines of the vehicle and for absorbing energy in the event of occupant-to-glazing impact. Due to the passivity requirement, the effect of active belts in providing lateral restraint was not investigated. Furthermore, determining the effectiveness of passive restraint systems such as air bags or passive belts in providing lateral collision protection was beyond the scope of the study.

A major part of the program involved determining the crashworthiness performance of a conventional late model, full-size automobile under intersection-type lateral collision conditions The impact test conditions were prescribed by NHTSA "on the basis of accident statistics, to be representative of types of lateral impact conditions that are resulting in serious injuries and fatalities" (Statement of Work). These test conditions constitute a method of simulating the general case of lateral collision wherein both vehicles are initially in forward motion, including both perpendicular and oblique collision angularities.

A parallel effort focused on the design and developmental testing of glazing of laminated construction with peripheral support structure that could provide a reasonable alternative to the monolithic tempered glass presently used for side glazing in virtually all motor vehicles. Development of deformable interior sidewall surfaces essentially expanded upon results of previous research programs (Refs. 2 and 3), in which material selection, component design and impact performance were reasonably well established.

Crash testing of the vehicles containing structural, glazing and interior modifications was performed in such a manner that comparison with the baseline test results provide an assessment of the effectiveness of the modified vehicle performance under the generally more severe cases of the baseline test configurations. Furthermore, the test matrix was defined such that the individual and combined effects of the structural and interior modifications could be ascertained for the case of perpendicular lateral impact.

The remainder of this report is organized as follows. Test methodology is described in Section 2, followed by the results of baseline testing discussed in Section 3. Vehicle modifications (structural, interior and glazing) are described in Section 4. Section 5 presents results of the modified vehicle testing. A general discussion of results is contained in Section 6. Conclusions and recommendations are given in Section 7. Complete test data is provided in the Appendices (Volume II).

2. TEST METHODOLOGY

This section describes the methodology employed for the lateral impact testing. Specific test conditions were prescribed by NHTSA. The general testing and data acquisition methods described in the following represent the current state-of-the-art and are consistent with previous lateral impact testing performed by Calspan (e.g., Refs. 2 and 4). Additional details relating to the test methodology are described in Ref 5

2.1 Test Configurations

The general lateral collision configuration illustrated in Figure 1 (taken from Statement of Work) is intended to simulate a realistic impact condition wherein both cars are in forward motion at impact. In actual crash testing, however, the struck vehicle is positioned at rest prior to impact. The desired relative impact condition is achieved by providing an equivalent velocity vector and attitude for the striking vehicle.

The following specific impact parameters were prescribed in the Statement of Work and refer to the condition to be simulated represented by Figure 1(a).

Configuration No.	V_1 (MPH)	V_2 (MPH)	ϕ (deg.)
1	0	30	0
2	30	30	0
3	0	30	30
4	30	30	30
5	0	40	0

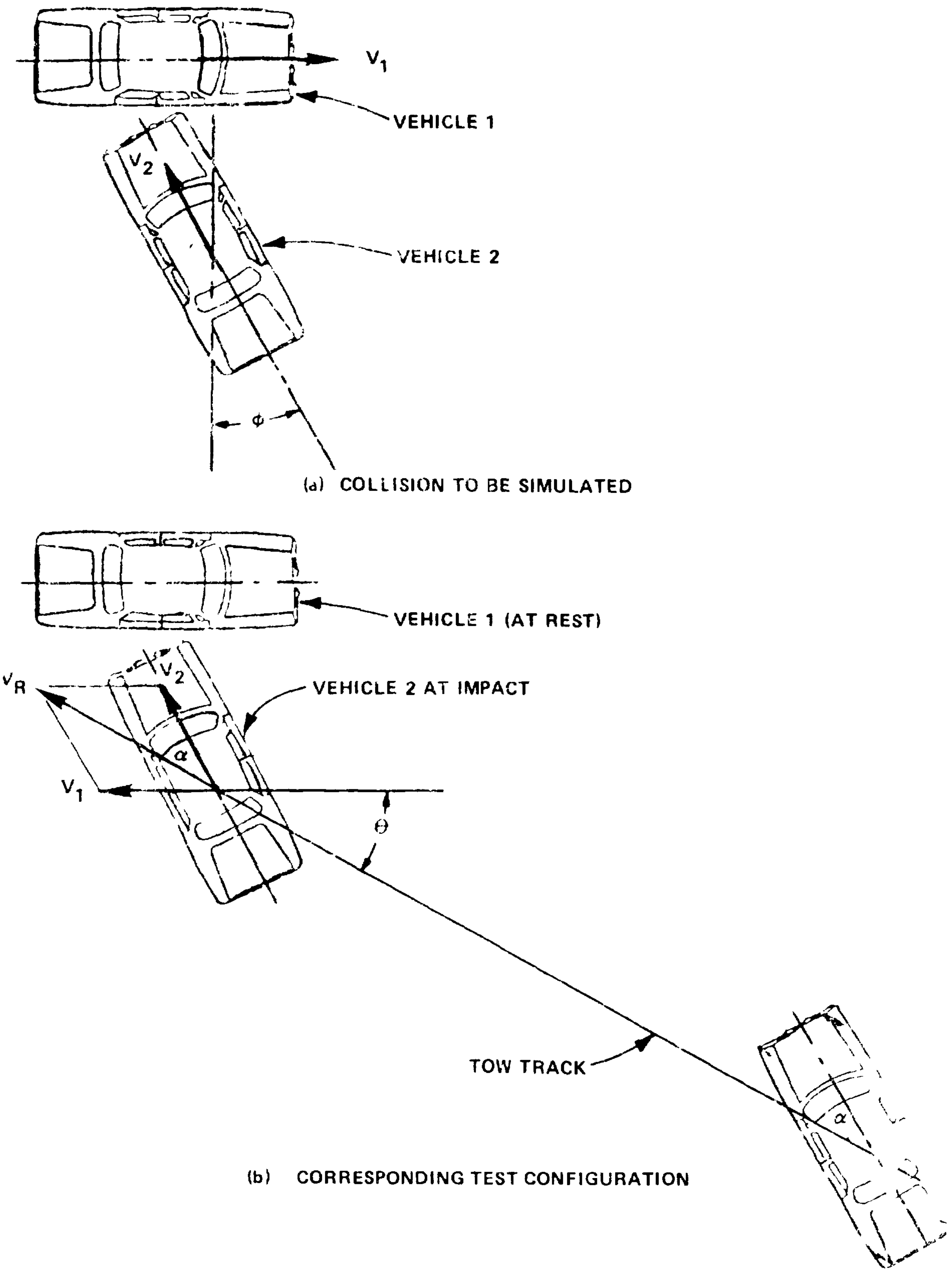


Figure 1 EXPLANATION OF TECHNIQUE TO SIMULATE COLLISION

Translating these conditions to the corresponding test configuration represented by Figure 1(b) results in (based on trigonometric relationships):

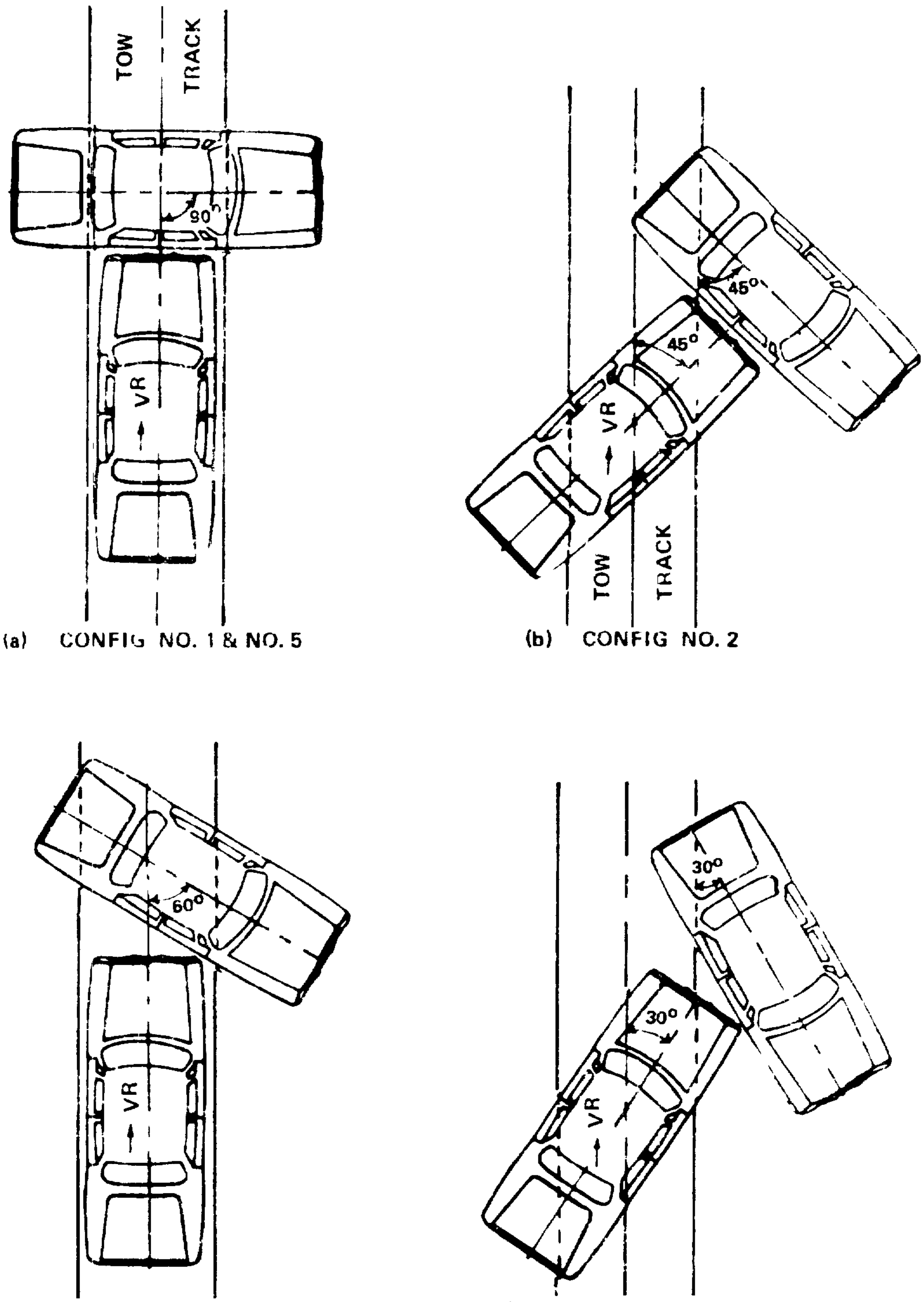
Configuration No.	$-V_1$ (MPH)	V_2 (MPH)	V_R (MPH)	α (deg.)	θ (deg.)
1	0	30	30	0	90
2	30	30	42.4	45	45
3	0	30	30	0	60
4	30	30	52	30	30
5	0	40	40	0	90

where V_R is the resultant velocity (tow speed) of the striking vehicle, α is the angle between the striking vehicle longitudinal axis and the tow track centerline, and θ is the angle between the struck vehicle longitudinal axis and the tow track centerline. Note that for configurations No. 2 and 4 (where $\alpha \neq 0$), the striking vehicle must be placed on auxiliary wheels to achieve the necessary impact attitude

Figure 2 illustrates the vehicle configuration for each test condition. Struck vehicles were, with one exception, impacted on the passenger (right) side. The vehicles were positioned such that the right side edge of the striking vehicle moved along a line passing through the Door Opening Reference (DOR) Point of the struck vehicle (defined by SAE Recommended Practice J972a) Impact locations for the specific vehicle employed and test condition angularities are shown in Figure 3.

2.2 Test Vehicles

The test vehicles were 1973 Ford 4-door, pillared hardtop automobiles having a nominal curb weight of 4300 lbs. Fuel tanks were removed as a precautionary measure. For the automobiles used as striking vehicles, the bumper reinforcing bar was replaced by the corresponding 1974 Ford assembly in order



(c) CONFIG NO 3

(d) CONFIG NO 4

Figure 2 VEHICLE CONFIGURATIONS FOR LATERAL IMPACT TESTS

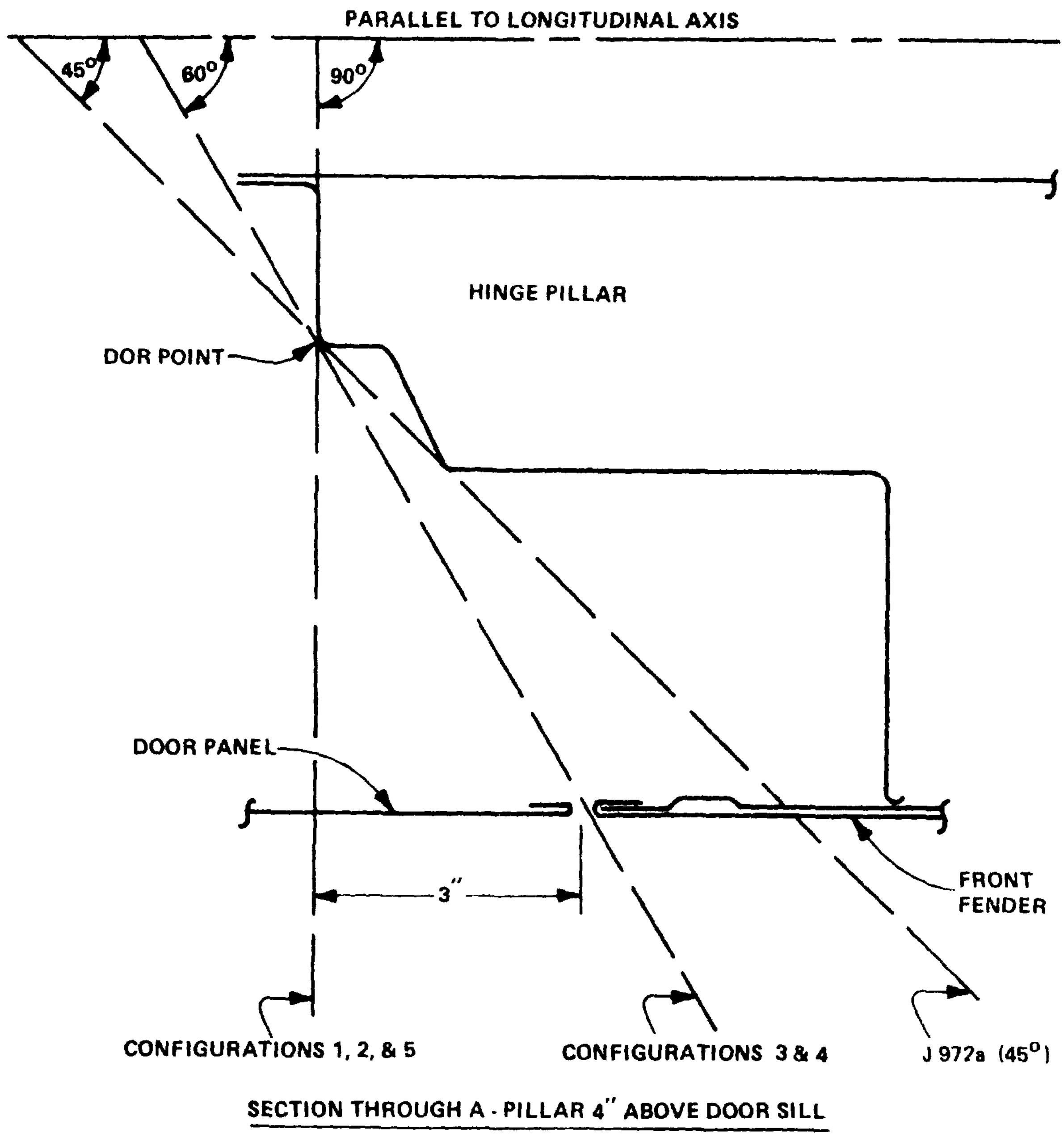


Figure 3 DEFINITION OF DOR POINT AND LINES ALONG THE RIGHT SIDE OF THE STRIKING VEHICLE

to simulate the higher strength of the 1974 bumper system* (all other front structure is virtually identical for the 1973 and 1974 model years) Struck vehicles were either conventional or modified 1973 Fords, as required for the baseline (see Section 3) and modified vehicle (see Section 5) test program.

In order to perform the tests requiring an oblique striking vehicle impact orientation, auxiliary wheel assemblies were used to support the vehicle at the desired yaw angle To compensate for the additional weight of these structures (approximately 350 lbs.) the rear axle, rear suspensions and drive shift were removed All four conventional wheels were removed so that the normal ride height (ground clearance) could be maintained The auxiliary wheel assemblies were attached to the vehicle in such a manner that no artificial stiffening of the forward structure resulted

In all crash tests, vehicles were propelled along a guiderail by a cable towing system employing a ground-based powerplant and automatic speed control A trailing cable arresting system provided an abort capability in the event of an unacceptable vehicle speed or other system anomalies Just before the time of impact, the vehicle in motion was released from the towing and guidance system so that no external loads, other than at the tire/ground interface, were introduced In addition, the striking vehicle arresting system was activated approximately 100 msec after the primary collision to prevent possible multiple impacts

2 3 Anthropomorphic Dummies

The following 50th percentile male anthropomorphic dummies were placed in the respective test vehicles in conventional seating positions

* The 1973 bumper reinforcement is basically channel-shaped whereas the corresponding 1974 assembly has a closed cross-section with additional end supports

Vehicle	Dummy Type	Location	Restraint
Striking	Sierra Model 292-850	Lt front & Rt. front	Conv. lap & shoulder belts
Struck	Humanoid Part 572	Front and rear on impacted side	None

Dummies contained in the struck vehicles (on the impacted side) were oriented in a consistent manner with respect to the following lateral dimensions corresponding to conventional and modified interior vehicles, respectively.

CONVENTIONAL INTERIOR*

Dummy	Measurement	Dimension (in.)
Front	Head to door glass	10.5
Front	Upper arm to door panel	6.0
Front	Hip to door panel	8.5
Front	Hip to arm rest	5.0
Rear	Head to C-pillar panel	10.0
Rear	Upper arm to sidewall	6.5
Rear	Hip to door panel	8.5

MODIFIED INTERIOR*

Dummy	Measurement	Approx. Dimension (in.)
Front	Head to door glass	10.5
Front	Upper arm to door padding	2.0
Front	Hip to door padding	4.5
Front	Hip to padded arm rest	3.0
Rear	Head to C-pillar padding	8.0
Rear	Upper arm to sidewall padding	2.5
Rear	Hip to door padding	4.5

* Dummies were positioned in the same manner with respect to the seat geometry for all conventional and modified vehicles; differences in lateral dimensions result from the addition of padding materials to the interior sidewall. Head to ceiling distances were approximately 4" and 3" for the front and rear seat dummies, respectively. Forehead to windshield distance was approximately 18" for all front seat dummies.

The front-seated dummy (struck car), due to high spinal stiffness, appeared to be unrealistically oriented with respect to head fore-aft location (excessively rearward) with the seat in mid-position, the front seat was therefore adjusted to the full forward position in all cases.

2.4 Instrumentation

Test vehicles and dummies were instrumented with accelerometers as indicated below

Striking Vehicle

Compartment floorpan left front corner (triaxial)
Compartment floorpan right rear corner (triaxial)
Bumper on ℄ behind reinforcement bar (x-axis)
Firewall near ℄ (x-axis)

Struck Vehicle

Compartment floorpan on driveline tunnel behind front seat (triaxial)
Compartment floorpan left front corner (triaxial)
Compartment floorpan left rear corner (triaxial)
Left front door on ℄ 6" below windowsill (y-axis)
Right front door on ℄ (y-axis)*
Firewall near ℄ (triaxial)
Front dummy head (triaxial)
Front dummy chest (triaxial)
Front dummy pelvis (y-axis)
Rear dummy head (triaxial)
Rear dummy chest (triaxial)
Rear dummy pelvis (y-axis)

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*At one or more locations on door, as required for a particular test

Examples of accelerometer locations are shown in Figure 4

A Hamilton Rolamite crash sensor was mounted on the firewall of each struck vehicle to provide an indication of the sensitivity of the sensor to lateral impact accelerations. This sensor was previously evaluated in a Calspan research program under NHTSA sponsorship (Ref. 6).

All power supply and signal conditioning equipment was contained in the trunks of the test vehicles

2.5 Data Processing and Reduction

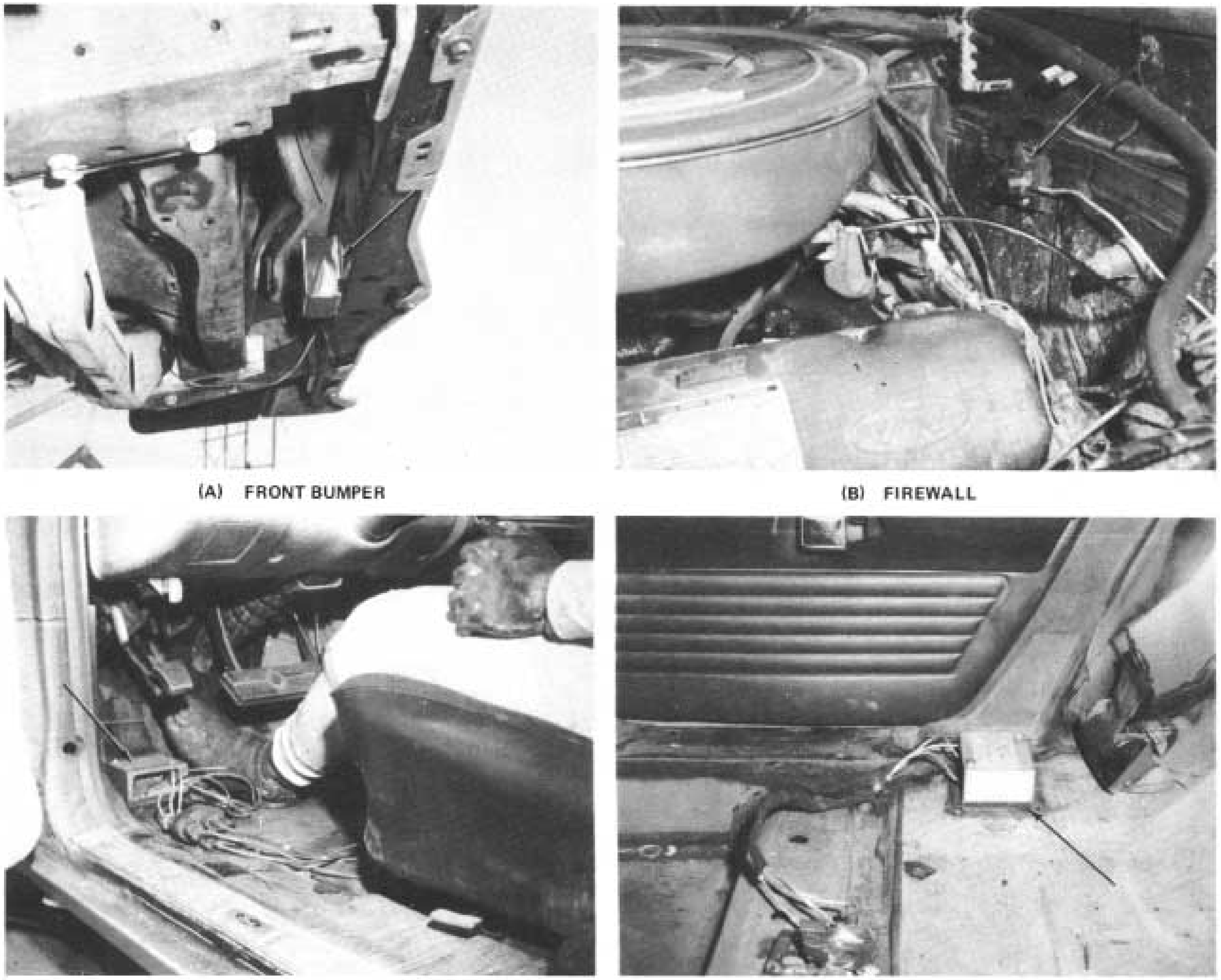
All acceleration data were processed and filtered in accordance with SAE Recommended Practice J211a as indicated below

Data Type	SAE J211a Channel Class
Vehicle Acceleration	60
Dummy head acceleration	1000
Dummy chest acceleration	180
Dummy pelvis acceleration*	180

The Calspan data processing and reduction system is described in Ref. 7 Basically, the data were recorded on FM tape, processed through an analogue-to-digital conversion system, and reduced (filtered, integrated, plotted, etc) in a digital format

Complete data in final form for all crash tests performed within this program are contained in Appendices A and B

*Not specifically defined by SAF J211a



(A) FRONT BUMPER

(B) FIREWALL

(C) LEFT FRONT FLOORPAN

(D) RIGHT REAR FLOORPAN

Figure 4 EXAMPLES OF ACCELEROMETER LOCATIONS

3. BASELINE TESTING

Table 1 lists the baseline tests that were performed. Tests No. 1 through 5 directly correspond to the prescribed test configurations defined in Section 2.1 Test No. 6 was a repeat of configuration No 3 except that a moving barrier* was substituted for the striking automobile Test No. 7 was a repeat of configuration No. 4 except that the impact location on the struck vehicle was moved forward approximately 10 inches from the previous DOR location to determine the effect of engaging more of the stiffer structure in the region of the A-pillar.

As discussed in Section 2.2, the striking vehicles were 1973 Ford 4-door automobiles with the bumper reinforcement structure replaced by the strengthened 1974 Ford bumper assembly. Test weight of the striking vehicles, except for the moving barrier, was approximately 4500 lbs. in all cases (ballast added in trunk when necessary to achieve this weight). The moving barrier weighed approximately 4000 lbs., consistent with the requirements of FMVSS No. 208 (S8.2.1). The conventional 1973 Ford 4-door automobiles employed as struck vehicles weighed between 4650 and 4840 lbs. as tested (no ballasting), somewhat heavier than the striking vehicles due to additional instrumentation and on-board photographic equipment.

Appendix A contains complete test descriptions and data for each of the baseline crash tests, including the following information:

- description of test conditions
- post-test observations

* The moving barrier was equipped with a contoured impact surface in conformance with SAE J972a Recommended Practice (see Ref. 8 for design details)

Table 1
BASELINE TESTS

TEST NO	CONFIGURATION NO.*	IMPACT SPEED (MPH)		VEHICLE TEST WEIGHT (LBS)	
		TARGET	ACTUAL	STRIKING	STRUCK
1	1	30.0	29.4	4500	4650
2	2	42.4	44.5	4500	4720
3	3	30.0	29.7	4500	4820
4	4	52.0	51.7	4500	4790
5	5	40.0	37.3	4480	4790
6	3**	30.0	29.6	4050	4820
7	4***	52.0	51.9	4500	4840

*DEFINED IN SECTION 2.1
**MOVING BARRIER USED AS STRIKING VEHICLE
***IMPACT POINT ON STRUCK VEHICLE MOVED FORWARD 10"
FROM THE IMPACT POINT FOR TEST NO 4

- vehicle and dummy photographs

- vehicle exterior deformation profiles

- passenger compartment static intrusion measurements

- vehicle acceleration responses and integrated velocity and displacement time histories

- Part 572 dummy (in struck vehicle) acceleration responses, integrated velocity and displacement time histories, head and chest severity indices and HIC* numbers

Table 2 summarizes test results which characterize the structural and glazing performance of the baseline vehicles. These results, however, reflect an extremely limited sampling of the available test information and the reader should consult Appendix A for a more complete understanding of the structural and glazing performance.

A summary of anthropomorphic dummy data is presented in Table 3 Information is given pertaining to dummy containment within the passenger compartment,** region of head contact as determined by the physical evidence, relative velocity of head contact (when contact occurred and where the velocity could be calculated with reasonable accuracy from film analysis), and the peak acceleration responses and associated injury indicators. The specified injury

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* Head Injury Criteria as defined in FMVSS No. 208.

** Successful dummy containment indicates that "all portions of the test device (were) contained within the outer surfaces of the vehicle passenger compartment throughout the test" (FMVSS No. 208).

Table 2

SUMMARY OF STRUCTURAL AND GLAZING PERFORMANCE

TEST NO	MAX STATIC CRUSH (IN)		STRUCK VEHICLE STATIC INTRUSION (IN)			STRUCK VEHICLE LATERAL ACCELERATION (g)**		TIME OF GLAZING FRACTURE (MSEC)	
	STRIKING	STRUCK	FRONT DOOR*	REAR DOOR*	MAX	AVERAGE	PEAK	FRONT DOOR	REAR DOOR
1	5.0	13.5	4.0	5.8	9.5	6.1	18.5	44	–
2	8.2	10.8	2.8	5.1	6.8	5.9	17.0	–	49
3	8.0	25.5	8.0	5.0	20.0	3.7	10.6	45	68
4	16.0	16.0	3.9	10.6	14.3	3.9	13.2	33	51
5	7.6	23.0	6.4	9.0	14.8	11.0	17.3	37	41
6	0	19.0	10.8	4.8	11.3	6.0	22.8	21	59
7	22.5	14.3	5.5	6.8	8.9	4.0	12.2	44	66

*CENTERLINE OF DOOR AT MID LEVEL

**DETERMINED FROM ACCELEROMETER MOUNTED ON FLOOR PAN TUNNEL BEHIND FRONT SEAT (PEAK VALUES BASED ON A 3 MSEC CLIP)

Table 3

SUMMARY OF ANTHROPOMORPHIC DUMMY DATA FOR BASELINE LATERAL COLLISION TESTS

PARAMETER		INJURY CRITERIA*	DUMMY IN RIGHT FRONT SEAT						
			TEST NO 1	TEST NO 2	TEST NO 3	TEST NO 4	TEST NO 5	TEST NO 6	TEST NO 7
CONTAINMENT OF DUMMY		–	YES	YES	YES	YES	YES	YES	YES
HEAD RESPONSE	PRIMARY CONTACT LOCATION	–	ROOF SIDE HEADER	ROOF SIDE HEADER & A-PILLAR INTERSECTION	NONE	WINDSHIELD & DASH PANEL	NONE	NONE	NONE
	TIME OF CONTACT * (msec)		147	91		153/175		–	–
	CONTACT VELOCITY** (mph)	–	6.1	7.8		14.6	–	–	–
	HIC NUMBER	1000	28	50	65***	78	130***	215***	66***
	A P ACC (g)	–	7	27	4	26	3	16	6
	L R ACC (g)	–	16	12	19	*12	25	36	27
	S I ACC (g)	–	8	24	28	26	36	49	31
	RESULT ACC (g)	–	15	36	30	34	39	56	39
CHEST RESPONSE	A P ACC (g)	60	6	8	10	17	7	16	9
	L R ACC (g)	45	35	26	42	26	$\boxed{46}$	$\boxed{63}$	$\boxed{61}$
	S I ACC (g)	20	8	9	11	13	9	13	10
	RESULT ACC (g)	60	39	28	45	26	48	$\boxed{66}$	$\boxed{61}$
PELVIC RESPONSE	L R ACC (g)	–	33	26	38	22	86	56	37

PARAMETER		INJURY CRITERIA	DUMMY IN RIGHT REAR SEAT						
			TEST NO 1	TEST NO 2	TEST NO 3	TEST NO 4	TEST NO 5	TEST NO 6	TEST NO 7
CONTAINMENT OF DUMMY			YES	YES	YES	YES	YES	YES	YES
HEAD RESPONSE	PRIMARY CONTACT LOCATION		C PILLAR	C PILLAR	C PILLAR	C PILLAR	C PILLAR	C PILLAR	C PILLAR
	TIME OF CONTACT (msec)		87	63	106	96	63	80	96
	CONTACT VELOCITY (mph)		N/A	19.7	14.8	13.7	15.8	N/A	N/A
	HIC NUMBER	1000	64	180	419	645	161	110	537
	A P ACC (g)		18	32	31	53	7	8	48
	L R ACC (g)		17	28	79	72	30	30	87
	S I ACC (g)		27	34	34	50	28	19	41
	RESULT ACC (g)		37	40	94	104	37	32	100
CHEST RESPONSE	A P ACC (g)	60	8	7	12	7	8	14	13
	L R ACC (g)	45	44	$\boxed{61}$	38	$\boxed{67}$	$\boxed{72}$	35	$\boxed{47}$
	S I ACC (g)	20	8	14	9	11	4	3	7
	RESULT ACC (g)	60	45	$\boxed{62}$	41	$\boxed{70}$	$\boxed{73}$	35	47
PELVIC RESPONSE	L R ACC (g)		51	42	16	54	68	17	22

*AS SPECIFIED IN WORK STATEMENT
**OBTAINED FROM FILM ANALYSIS
***DOES NOT RESULT FROM CONTACT WITH VEHICLE STRUCTURE
N/A CANNOT BE ACCURATELY DETERMINED FROM PHOTOGRAPHIC COVERAGE

NOTE GIVEN ACCELERATION MAXIMA ARE EXCEEDED ONLY FOR TIME INTERVALS NO GREATER THAN 3 MILLISECONDS criteria were prescribed in the Statement of Work by NHTSA based on biomechanical information and, for the purposes of this program, were interpreted as being approximate threshold values above which very serious or fatal injury would be expected. The dummy responses that exceeded a particular injury criterion are denoted in Table 3 (note boxed-in values).

The Hamilton Rolamite (Serial No. 2164) crash sensor mounted on the firewall of the struck vehicle (oriented longitudinally) triggered in only one instance. This occurred in Test No. 7, where an activation signal was indicated 42.5 msec after initial vehicle contact (time zero). Triaxial acceleration data were obtained from transducers mounted to the same fixture as the crash sensor (data contained in Appendix A). The acceleration pulse to which the crash sensor was subjected can therefore be correlated with the sensor response

4. VEHICLE MODIFICATION

This section describes the structural, glazing and interior modifications relating to lateral impact protection that were employed in the modified test vehicles. The structural modifications were developed previously. This research program was principally directed towards the developmental testing of advanced glazing and interior padding modifications.

4.1 Structure

Structural modifications employed in the struck vehicles were developed in previous NHTSA research programs by Calspan (Refs. 2 and 3). In general, the modification effort was restricted to structural components developed primarily for side impact protection.* These components are illustrated in Figure 5 (labeled items only). As noted, the modifications are related both to the perimeter frame structure (3rd crossmember and longitudinal struts) and the body structure (side pillars, door beams and roll bar).

Further descriptions of each structural modification are given below:

- 3rd frame crossmember

This structure was designed to provide additional lateral support to the frame siderails near mid-span (B-pillar location) and to dissipate energy through bending when the siderails deflect laterally. The longitudinal struts serve as additional stiffening elements (also related to front structure performance).

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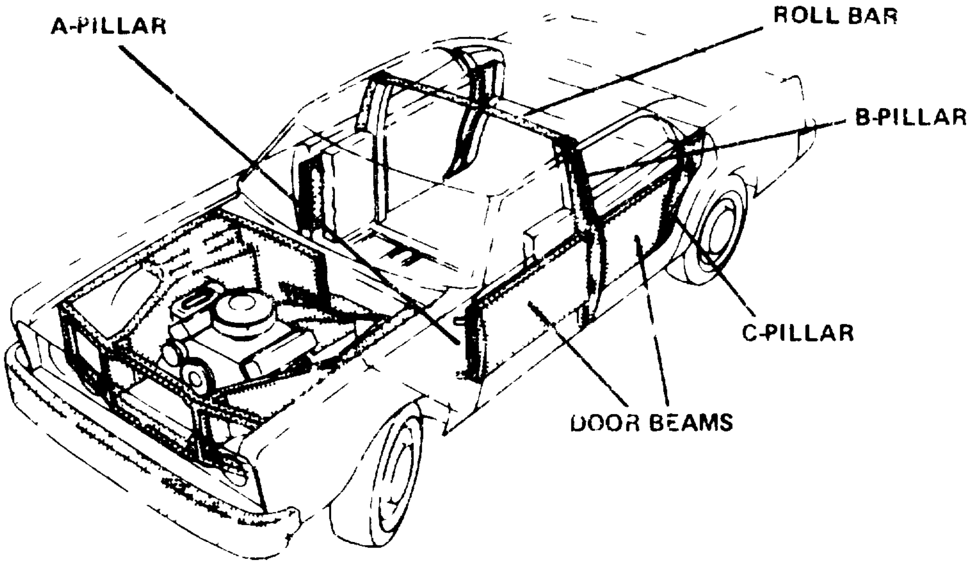
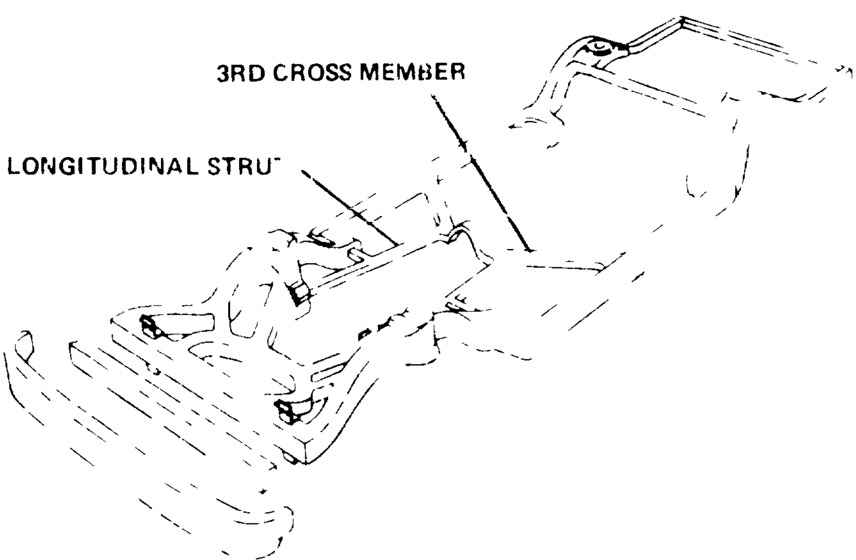
* These structural modifications are also functional to some extent in other accident modes, e.g., frontal and rollover collisions.



(a) BODY MODIFICATIONS



(b) FRAME MODIFICATIONS

Figure 3 STRUCTURAL MODIFICATIONS

- A-pillar

This modification involved strengthening of the A-pillar structures to provide increased support for the front door hinge attachment hardware. Increased metal thickness of the interior and exterior pillar surfaces was needed, but no significant geometric changes were required due to the inherent strength of the conventional box-like configuration. A thin-walled tubular member was added to the upper firewall between the A-pillars to simulate additional lateral strength resulting from a reinforced firewall structure.

- B pillar

Modification of the B-pillar required increasing the bending strength, providing attachment points for the front door latch and rear door hinge hardware, and insuring effective load transfer to the roof, floorpan and frame. With respect to the frame load path, the lower B-pillar was designed to overlap the frame side rail, thus bearing directly against the side rail when laterally loaded.

- C-pillar

This modification involved strengthening of the conventional C-pillar structure to provide the required support for the rear door latch attachment hardware. Increased metal thicknesses in certain areas and more extensive continuous seam welding of the conventional sheet metal components were required.

- Roll bar

A thin-walled tubular structure was installed between the upper B-pillars to increase the lateral strength of the roof. This modification obviously relates also to rollover protection.

Door beam panels

High strength-to-weight panel structures (three cell corrugated shape) were incorporated into the doors in the available space between the glass stowage mechanism and the outer door skin. These structures were designed to cover nearl the entire lower door areas The panels were attached directly to the door retention hardware (strengthened hinges and modified latches) to provide effective load transfer to the respective side pillars. Figure 6 shows how the panels were designed to engage the bumper and front sheet metal of a striking vehicle.

The net weight increase resulting from these structural modifications to a 1973 Ford automobile is approximately 200 lbs It should be noted that this weight penalty could be reduced significantly if the design changes were more effectivel integrated with the production vehicle structure instead of largely representing add-on modifications. The reader should consult Ref 3 for a more detailed description of the structural modifications and weight breakdown

4 2 Glazing

This effort involved the design and testing of laminated side glazing and peripheral support structure to be installed in the modified test vehicles Since the 1973 Ford base vehicles have no upper door frames (unsupported glass), the design of support structure was necessary The laminated glass was selected on the basis of providing a representative variety of constructions and [illegible] types, within the limits of availability, time and funding constraints It was also required to design the glazing and support structure such that the roll down operation of the side window could be preserved.

4 2 1 Design and Headform Impact Testing

Peripheral support structure for side glazing was designed and [illegible] Figure 7 shows the frame structure and the test fixture used for headfor

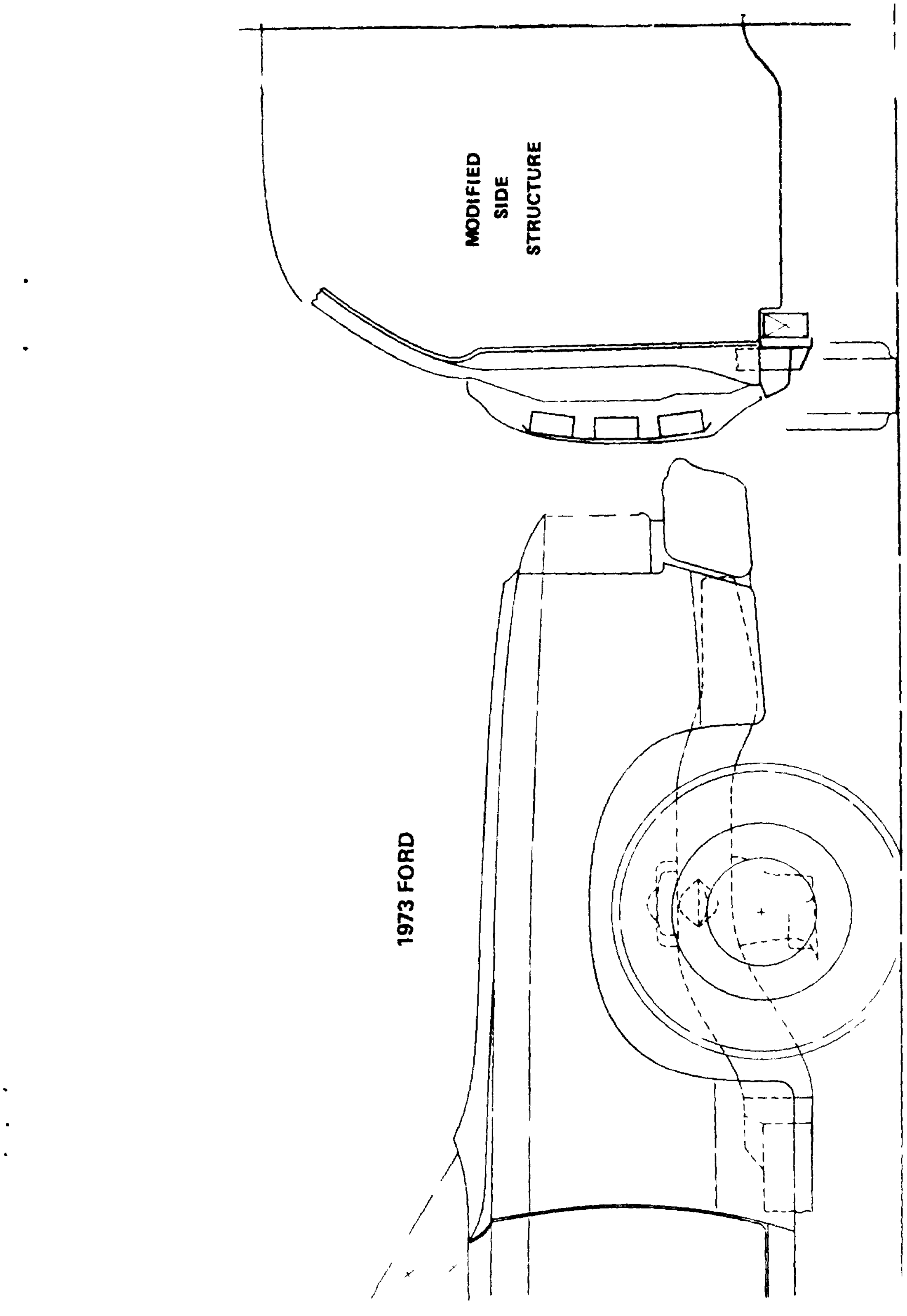


Figure 6 RELATIVE LOCATION OF FRONT AND SIDE STRUCTURES

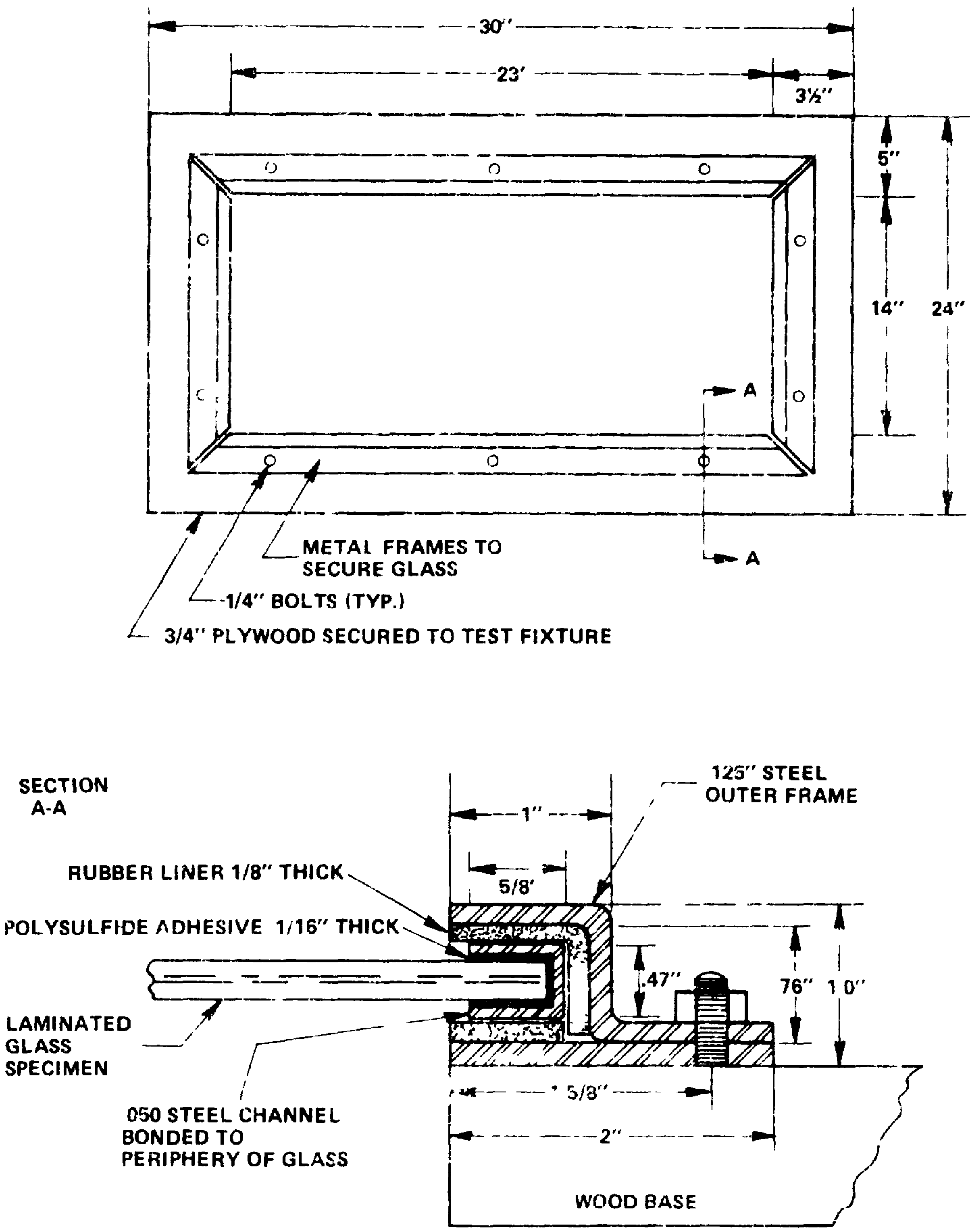


Figure 7 DESIGN OF GLASS FRAME STRUCTURE AND IMPACT TEST FIXTURE

impact tests (vertical drops). The outer frame lined with 1/8" rubber represented the upper door frame structure. The glass laminate was directly supported by the 050" steel channel bonded to the glass with polysulfide adhesive.* Since no clamping pressure was applied to the peripheral channel, this configuration simulated a movable side window configuration The peripheral channel was designed to support a 030" polyvinyl butyral (PVB) interlayer stretched as a membrane to a tensile stress of 3000 psi (nominal ultimate tensile strength of PVB)

Three impact tests were performed using an adult (15.5 lb.) headform. Laminated annealed glass was used with a .030" PVB interlayer and each glass ply thickness approximately .110" (HPR windshield type) Test conditions were as follows

Test No	Configuration	Impact Velocity (MPH)
1	4 sided frame	20.0
2	3 sided frame	20 0
3	3 sided frame at partial roll-down	20.0

Figure 8 shows the test of the four-sided frame structure, for which full retention of the glass was maintained Figure 9 shows the test of the three-sided frame structure, which simulated a free edge corresponding to the bottom of the glass as installed in a door (normally bolted to roll-down mechanism) Full retention of the glass was also maintained with this support configuration. Figure 10 shows the test of the three-sided channel structure

* Supplied by Thiokol Corporation, Chemical Division, Trenton, N.J.

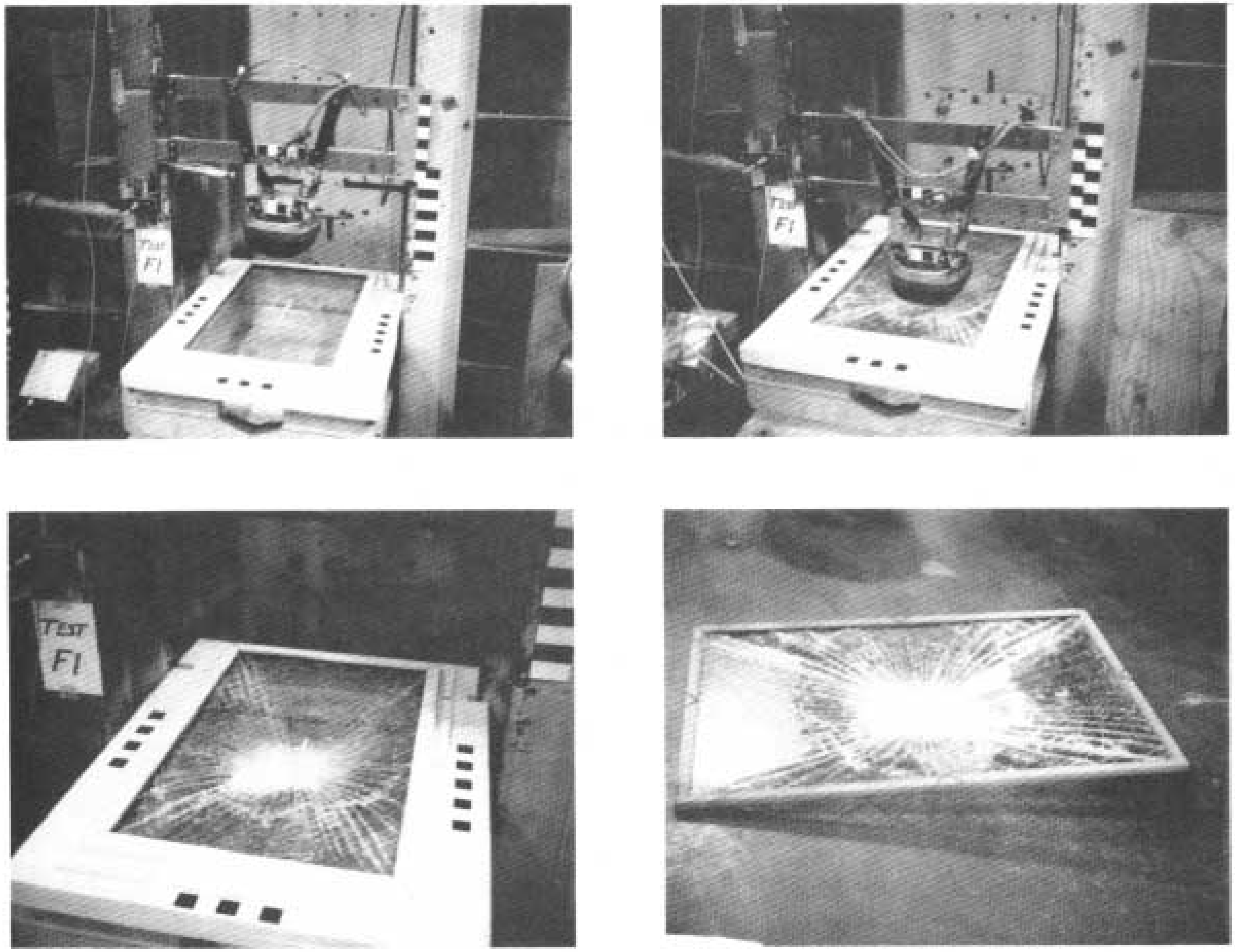


Figure 8 HEADFORM IMPACT TEST OF FOUR-SIDED FRAME STRUCTURE (TEST NO. 1)

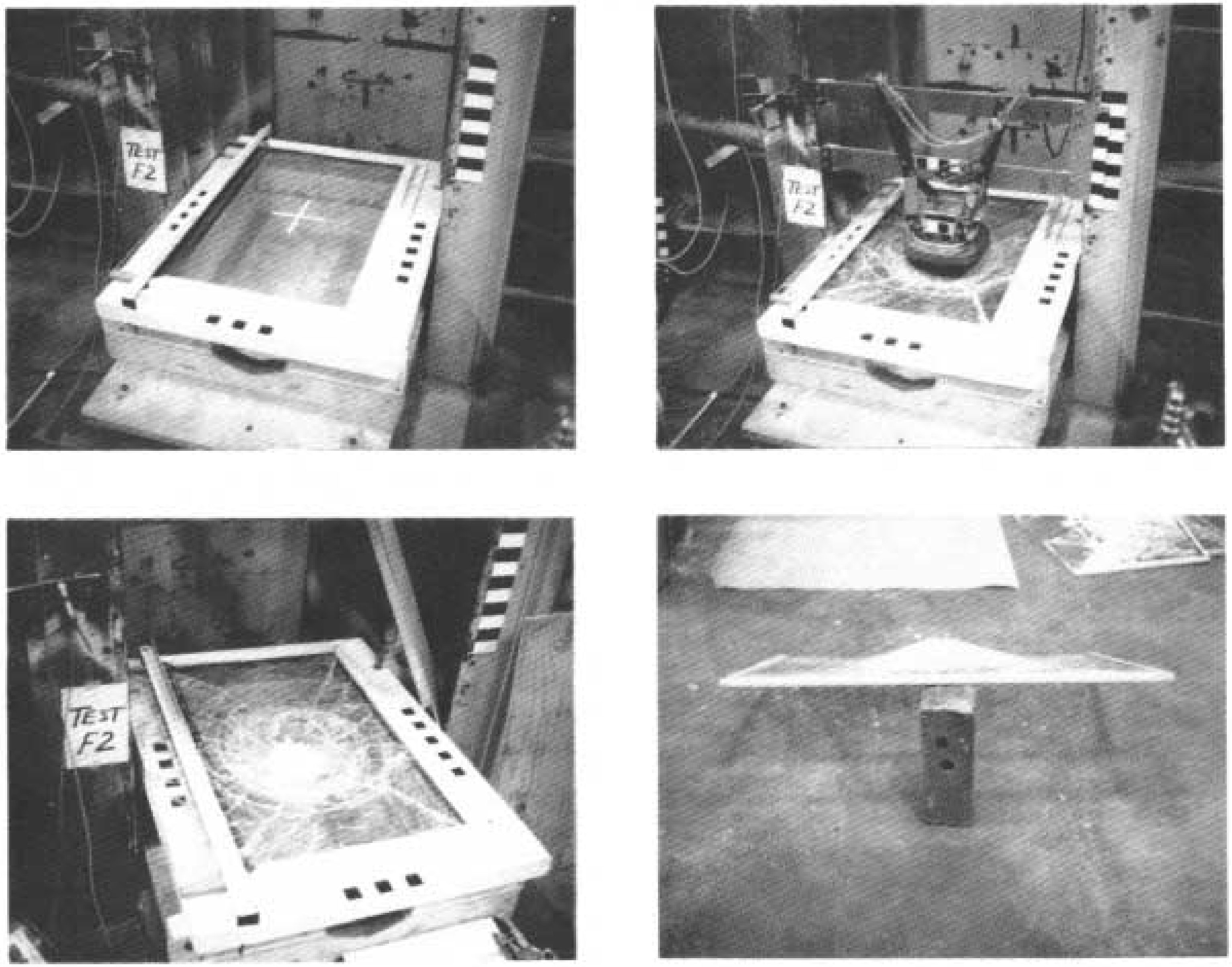


Figure 9 HEADFORM IMPACT TEST OF THREE-SIDED FRAME STRUCTURE (TEST NO. 2)

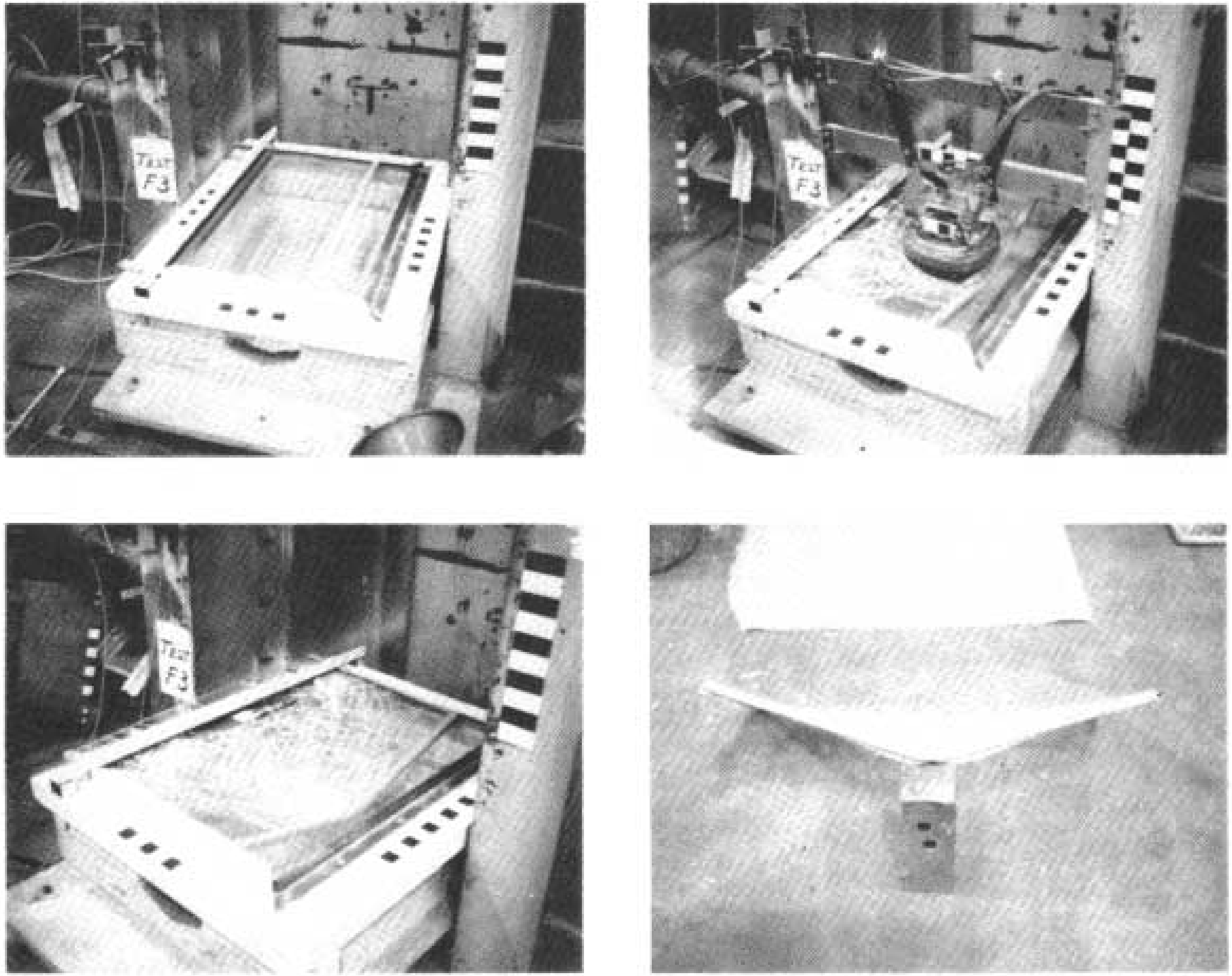


Figure 10 HEADFORM IMPACT TEST OF THREE-SIDED FRAME STRUCTURE IN A PARTIAL ROLL-DOWN CONDITION (TEST NO. 3)

in a simulated partial roll-down configuration, in which the headform impacted approximately 3" from the channel-supported edge. Again, full retention of the glass was maintained, although the supported edge deflected approximately 3.4".

The acceleration responses and associated velocity, displacement and severity index time histories are contained in Appendix C. Table 4 summarizes the pertinent test results.

Dynamic deflection of the PVB interlayer (head plow-in) was close to 5" in each case. No tearing of the interlayer or separation from the peripheral support frames occurred Short duration headform responses during glass breakage all appear to be in the neighborhood of 75 g's, indicating a nominal dynamic breakage load of 1200 lbs. (headform weight = 15.5 lbs.). In each case, the HIC number was well below the assumed human tolerance limit of 1000.

The important conclusion was that the channel-shaped frame bonded to the glass periphery was adequate to constrain the laminate within the simulated upper door frame structure during a 20 MPH head impact. Furthermore, the framed glass edge, when exposed to head contact when the window is partially rolled down, does not appear to pose an additional hazard.*

Laminated glazing materials** of the following constructions were subjected to additional impact testing at various velocities with both adult (7.5" dia., 15.5 lbs.) and child (6.5" dia., 7.5 lbs.) headforms.

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* The lacerative potential and the effect of striking the frame at angles other than the perpendicular were not investigated.

** All glazing specimens were furnished by PPG Industries, Pittsburgh, Pennsylvania, at no cost to the program.

Table 4

SUMMARY OF HEAD FORM DROP TEST DATA
(15 5 # HEAD FORM AT 20 MPH)

TEST NO	MAX STATIC DEFLECTION (in)	MAX DYNAMIC DEFLECTION (in)	MAX ACCEL (g)*	SEVERITY INDEX	HEAD INJURY CRITERIA**			
					NO	t_1 (sec)	t_2 (sec)	AVE ACCEL t_1 TO t_2
1	2 6	5 2	44	567	335	0003	0245	45 3
2	2 4	4 9	44	377	259	0005	0261	40 0
3	3 6	5 3	52	385	341	.0002	0391	37 8

*MAX FOR 3 MILLISECOND DURATION

**DEFINED IN FMVSS NO 208

Type	Inside Layer	Interlayer	Outside Layer
A-A (.015)	.105" annealed glass	.015" PVB	105" annealed glass
A-A (.030)	.115" annealed glass	.030" PVB	.115" annealed glass
T-T (.030)	5/32" (.156) tempered glass	.030" PVB	5/32" tempered glass
PPG bilayer*	.030" plastic	---	5/32" tempered glass

The specific test conditions and a summary of results are given in Table 5. All of these laminates had dimensions of 19-1/4" x 24-1/4" and were supported by three-sided frame structures as in Test No. 2 described above.

Acceleration response data and corresponding velocity and displacement time histories are contained in Appendix C. Cumulative Severity Index curves are also shown. It should be noted that no tearing of the interlayer occurred in any of the cases except for Test No. 13 (laminated annealed glass with .015" interlayer), in which complete head penetration occurred (circular shaped tear with approximately 28" circumference).

Two layers of moist chamois were applied to the adult headform for the 15 MPH impact tests to get an indication of the laceration potential of each type of laminate. Resulting Laceration Indices** are given below:

Test No.	Material Type	Laceration Index
5	A-A (.015)	1
17	A-A (.030)	2
10	T-T***	0
16	PPG bilayer	0

* This is an exposed plastic design, the plastic layer is a proprietary material under development by PPG Industries

** The procedure used is described in E. R. Plumat, et al., "Nonlacerating Glass Windshields--A New Improved Approach," 15th Stapp Car Crash Conference, November 1971.

*** No glass fracture occurred under this test condition.

Table 5

SUMMARY OF HEADFORM DROP TEST DATA

(19 1/4" x 24 1/4" LAMINATED GLASS WITH 3-SIDED FRAME SUPPORT)

MATERIAL TYPE	TEST NO	HEADFORM	IMPACT VELOCITY (MPH)	GLASS FRACTURE	MAX DEFLECTION (IN)		MAX ACCEL * (g)	SEVERITY INDEX	HEAD INJURY CRITERIA**			
					STATIC	DYNAMIC			NO	t_1 (SEC)	t_2 (SEC)	AVE ACCEL (g) t_1 TO t_2
A A (015)	4	ADULT	10	PARTIAL***		0 4	68	540	471	0009	0086	82 3
	5		15	YES	2 2	3 3	34	273	134	0002	0314	28.4
	12	CHILD	10	PARTIAL		0 5	62	420	313	0006	0087	68 3
	1		20	YES	COMPLETE PENETRATION		24	156	77	0080	0619	18 7
A A (030)	18	ADULT	10	YES	1 2	1 7	12	230	148	0006	0050	61 5
	17		15	YES	1 8	3 2	34	204	144	0002	0278	30 7
	2		20	YES	2 4	4 7	44	377	259	0005	0261	40 0
	19	CHILD	10	PARTIAL	–	0 4	56	420	323	0008	0077	74.0
	20		20	YES	1 5	2 2	60	1440	1256	0005	.0034	178.0
T T	9	ADULT	10	NO	–	0 4	61	1260	850	0008	0072	112 0
	10		15	NO	–	0 5	87	2400	1737	0006	.0083	138.8
	11		20	PARTIAL		0 6	100	3600	2660	0005	.0087	159 5
BILAYER (PPG)	6	ADULT	10	YES	1 7	3 2	30	115	56	0008	0058	41.8
	16		15	YES	2 0	5 1	35	280	172	0003	0414	28 1
	8		20	YES	2 3	6 4	45	556	314	0001	0371	37 3
	15	CHILD	10	NO		0 6	83	670	554	0011	0080	91 7
	14		20	YES	1 0	1 7	163	2200	1970	0008	0050	165.2

* MAX LEVEL FOR 3 MILLISECOND DURATION
** AS DEFINED IN FMVSS NO 208
*** PARTIAL FRACTURE BOTTOM GLASS PLY FRACTURED ONLY

Figure 11 shows the computed HIC numbers plotted as a function of impact velocity for each glazing type except for the thinner interlayer, two-ply annealed construction, which lacks sufficient penetration resistance. These results show that (a) the laminated tempered glass configuration possessed excessive breakage strength, (b) the two-ply annealed and bilayer constructions produced HIC numbers well within the assumed human tolerance limit for the adult headform impacts, and (c) the assumed human tolerance limit was exceeded for the child headform impacts of the two-ply annealed and bilayer constructions for impact velocities in excess of approximately 15 MPH. However, it is not known to what extent the assumed tolerance limit is meaningful in the case of a child

In summary, results of the impact tests indicated that Types A-A (.015) and T-T (.030) could be ruled out for modified vehicle side glazing application for the following reasons

Type A-A (.015) - The thin PVB interlayer (.015") lacks sufficient penetration resistance (child headform completely penetrated the material at 20 MPH).

Type T-T (.030) - The two-ply 5/32" tempered laminate* has excessive breakage strength (HIC numbers for the adult headform ranged from 850 for a 10 MPH impact to 2660 for a 20 MPH impact, neither of which caused complete glass fracture)

Type A-A (.030) and the PPG bilayer appeared to be suitable for modified vehicle application, at least on the basis of impact performance.

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* Technical representatives of Ford Motor Co. and PPG Industries have indicated that the 5/32" tempered glass thickness (each ply) is the minimum that could presently be considered for high volume production because of warpage problems with thinner plys during thermal tempering.

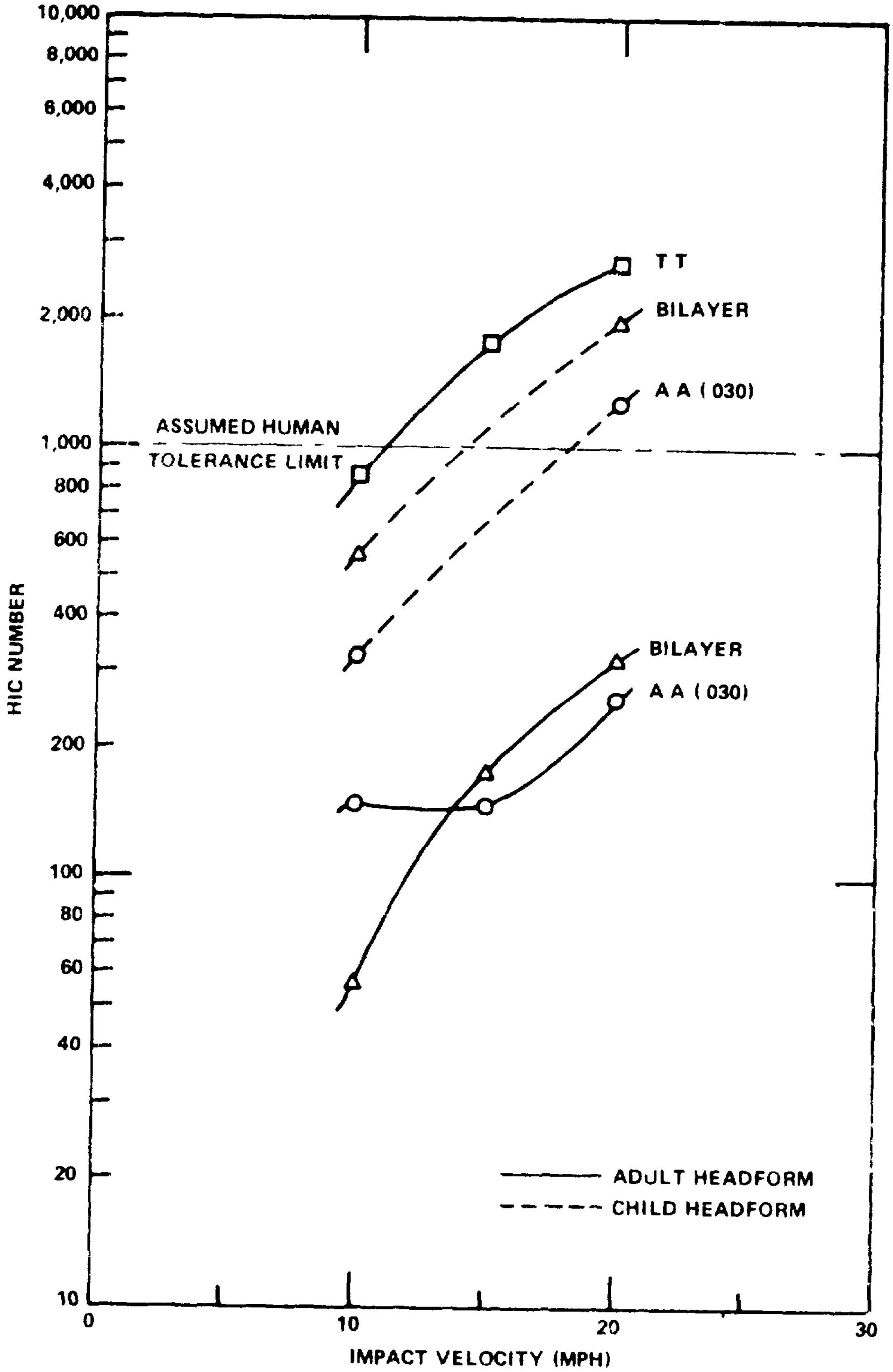

Figure 11 RESULTS OF HEADFORM IMPACT TESTS

4 2.2 Modified Vehicle Glazing Installation

Based on the headform impact test results presented in Section 4.2.1, laminated side glazing for the modified vehicles was limited to the following two types of construction:

Type	Inside Layer	Interlayer	Outside Layer
A-A (.030)	.100" annealed glass	.030" PVB	.100" annealed glass
PPG bilayer	.030" plastic	---	7/32" (.219) tempered glass

Note that the thicknesses of the glass plies vary somewhat from the corresponding laminated specimens subjected to headform testing. The reason for this is that the modified vehicle glazing needed to be fabricated with the same curvature as the conventional 1973 Ford front door sidelite, availability of glass which could be readily formed (or was already available) dictated use of the indicated glass ply thicknesses.*

The use of glazing that duplicated the conventional curvature was necessary in order to demonstrate rolldown operation of the framed, laminated side windows. Of course, the metal framing (both the upper door frames and peripheral channels bonded to the glass edge) needed to be fabricated with the corresponding shape and curvature of the conventional glass edge.** Figure 12 illustrates the design of the upper door frame and peripheral support structure. Installation of the operational laminated glazing was limited to

* The curved laminates were supplied by PPG Industries at no cost to the program.

** The fabricated metal frames were procured from Creative Industries of Detroit.

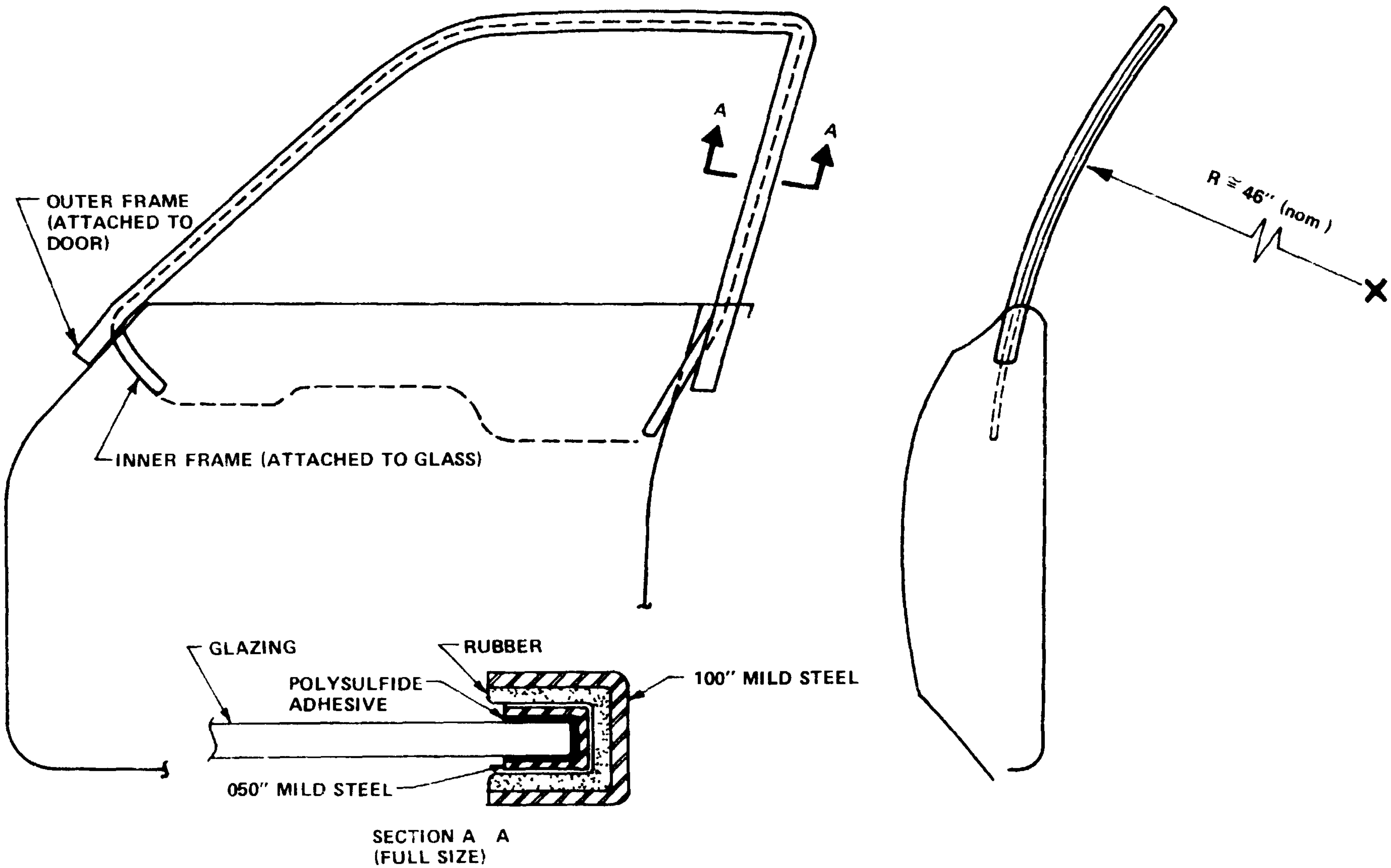

Figure 12 UPPER DOOR FRAME AND PERIPHERAL GLAZING SUPPORT STRUCTURE

the front door windows, rear door windows either retained the conventional monolithic tempered glass or were replaced by flat, fixed laminated glass.*

The two types of laminates employed are discussed in the following.

- Two-ply annealed glass with .030" PVB interlayer

This construction is essentially the same as presently used in all domestic automobile windshields. The PVB interlayer was increased in thickness from .015" to .030" and a controlled adhesion bonding process was introduced in the 1966-model domestic automobiles to provide increased penetration resistance (High Penetration Resistance construction). This construction (Type AS 1) meets all requirements of FMVSS No. 205 for use anywhere in motor vehicles. (Monolithic tempered glass, Type AS 2, can be used anywhere except in windshields.)

Prior to the late 1950's laminated annealed glass was also employed in side windows. The shift to monolithic tempered glass was believed to be made for one or more of the following reasons (a) substantially lower production cost, (b) annealed glass frequently required replacement because of its fragileness, and (c) evidence of excessive laceration injuries caused by the fracture properties of the annealed glass during lateral impacts. Monolithic

* This depended on the test condition. For the oblique lateral impacts where rear dummy glass contact was possible (although not likely), the flat laminated glass was installed in the rear door windows.

tempered glass apparently has been successful in reducing the replacement rate and laceration propensity, however, no containment of occupants is provided by this type of glass subsequent to fractur (characterized by fragmentation into small granules).

- PPG bilayer

This construction is one of several exposed plastic concepts currently being investigated by glazing manufacturers and others Advantages over two-ply glass laminates appear to be (a) reduced weight since only one glass ply is necessary, and (b) reduction or elimination of laceration potential due to the protective plastic layer on the inside surface The principal disadvantage is that plastic materials have abrasion resistance inferior to glass. Moisture absorption by the plastic and resistance to certain chemicals are also potential problems with exposed plastic glazing

The FPG bilayer construction,* in its present state of development, will not meet the FMVSS No 205 regulation, for use in motor vehicles at locations requisite for driving visibility, i e , generally all glass areas in automobiles (there are some exceptions) Specifically, the plastic material will not pass the abrasion resistance test (Test No 18) defined by the ANS** Z26 1-1969 specifications which

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* This bilayer construction is currently under development by PPG Industries Inc., for possible aircraft, automobile, or other commercial applications

** American National Standard "Safety Code for Safety Glazing Materials for Glazing Motor Vehicles Operating on Land Highways" constitute Section 5 1.1 of FMVSS No. 205. Indeed, to our knowledge, no existing plastic will pass this abrasion test (1000 cycle Taber Abraser) The question is whether or not this test condition, developed specifically for glass, can be relaxed for the inside glazing surface without compromising the requirement of a durable, optically acceptable light transmitting surface over a reasonable automobile service life. It should be noted, however, that the plastic material will pass the ANS Z26 abrasion test for plastics (Test No 17), but rigid and flexible plastics are presently allowed only in specific locations not requisite for driving visibility (with some exceptions).

As an important related consideration, there is evidence that the particular plastic material (PPG proprietary) possesses superior penetration resistance at high and low temperature extremes as compared with polyvinyl butyral (PVB), at room temperature the mechanical properties are believed to be similar.

Further study into the feasibility of exposed plastic glazing materials was beyond the scope of this program. In summary, it appears that an extensive review of FMVSS No. 205 requirements would need to be undertaken in order to establish whether or not glazing materials of this type would be acceptable as an alternative to traditional automotive glazing constructions

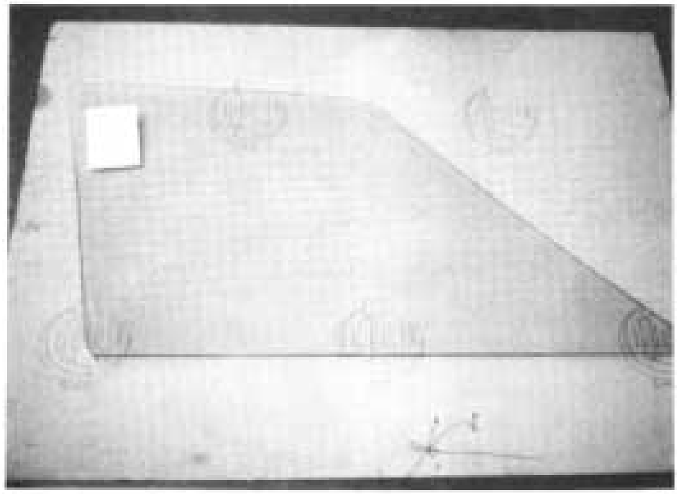
Installation of the two types of laminates required different methods to mount the glazing to the rolldown mechanism within the door cavity The conventional thermal tempered glass is bolted to the linkage mechanism through holes drilled along the bottom edge of the glass. The bilayer construction was similarly mounted since it is partially composed of tempered (strengthened) glass. The two-ply annealed laminate, since it does not possess adequate tensile strength, cannot be bolted in place because drilled holes cause stress concentrations which initiate crack propagation Thus, for this case, the laminate was fabricated with a straight bottom edge which was bonded to a sheet metal channel The metal structure was extended below the glass surface and contained the normal bolt pattern Figure 13 illustrates the shape difference for the two types of laminates (peripheral frame structure not shown)

Figure 14 shows a completed installation of supported, laminated glass in a modified 1973 Ford and demonstrates that the rolldown capability was preserved A total of five modified vehicles (designated A through F) were constructed and crash tested. Each vehicle contained a front door glazing installation similar to that shown in Figure 14 The following table indicates the specific type of side glazing employed in each modified test vehicle

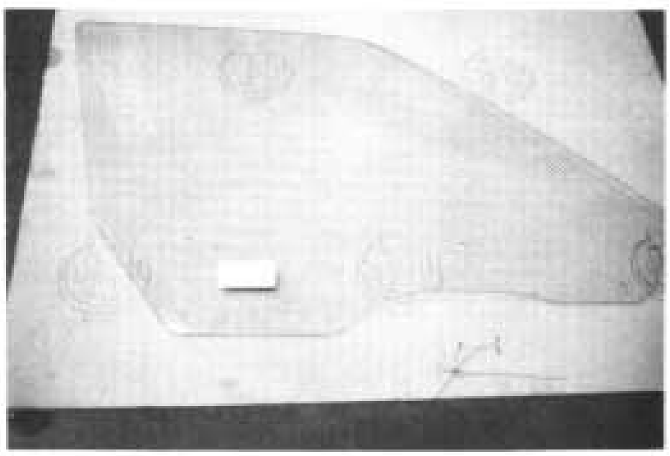
Modified Vehicle Designation	Glazing Installation Front Door	Rear Door
A	A-A (.030)	A-A (030)*
B	A-A (.030)	Conventional
C	A-A (030)	Conventional
D	PPG bilayer	Conventional
E**	A-A (030)	Conventional

* Fixed, flat glass laminate

** No structural modifications except for upper door frame



(a) ANNEALED GLASS LAMINATE (STRAIGHT BOTTOM EDGE)



(b) BILAYER (CONVENTIONAL SHAPE AND BOLT PATTERN)

Figure 13 FRONT DOOR CURVED GLAZING CONFIGURATIONS

(a) WINDOW CLOSED

(b) PARTIALLY OPEN

(c) WINDOW OPENED

(d) WINDOW CLOSED

Figure 14 OPERATIONAL GLAZING INSTALLATION

Vehicle A contained the glazing (and structural) modifications on both sides since it was subjected to two lateral impact tests Glazing modifications were restricted to one side of the remaining vehicles since these were laterally impacted on one side only

4.3 Interior

Modifications to the interior of the passenger compartment included crushable door panels and protective padding materials added to the sidewall areas subject to occupant contact under the specific lateral impact test conditions. This effort, for the most part, was based on an interior design previously developed by Calspan under Contract No. DOT-HS-053-2-487 (Ref. 3).

4.3.1 Padding Material Tests

As noted above, the interior design followed mainly from previous developmental efforts However, information was needed which more fully characterizes the performance of the various padding materials and constructions utilized in the interior modification. References 2 and 3 contain additional information that should be consulted for a complete understanding of the rationale behind the material selection and padding design. Refer to Section 4 3.2 for detailed descriptions of the actual materials and constructions used in the modified test vehicles.

Table 6 lists the static tests that were performed. The lateral body form was designed to simulate the nominal shape of a 50th percentile male torso laterally oriented with respect to the contacted surface The body form was constructed from hardwood and was shaped as a half cylinder with a diameter of 8 inches and a length of 31 inches. A covering of 1/2" Ensolite was added to the surface to provide some resiliency. For some of the tests, an arm removed from a Part 572 dummy was attached to the lateral body form to simulate the case where an occupant's arm is located between the occupant and the contacted sidewall surface Depending on the positioning of an occupant, it is

Table 6

STATIC TESTS OF PADDING MATERIALS

TEST NO	BODY FORM	MATERIAL	OVERALL DIMENSIONS** (IN)	MAX CRUSH BEFORE BOTTOMING* (IN)	MAX LOAD BEFORE BOTTOMING (LBS)
S1	LATERAL	1/2 ENSOLITE OVER 4 PAPER HONEYCOMB (3/8 CELL)	24 x 24	4 0	8000
S2	LATERAL	1/2 ENSOLITE OVER 4 PAPER HONEYCOMB (3 4 CELL)	24 x 24	3 9	2400
S3	LATERAL	CONTOURED DOOR PANEL (FIG 25)	15 x 24	5 2	4500
S4	LATERAL/ARM	1/2 ENSOLITE OVER 4 PAPER HONEYCOMB (3/8 CELL)	24 x 24	5 4	4800
S5	LATERAL/ARM	1/2 ENSOLITE OVER 4 PAPER HONEYCOMB (3/4 CELL)	24 x 24	5 2	1400
S6	LATERAL/ARM	CONTOURED DOOR PANEL (FIG 25)	15 x 24	6 0	2600
S7	LATERAL/ARM	4 S-00230 EXPANDED URETHANE	17 x 24	4 3	900

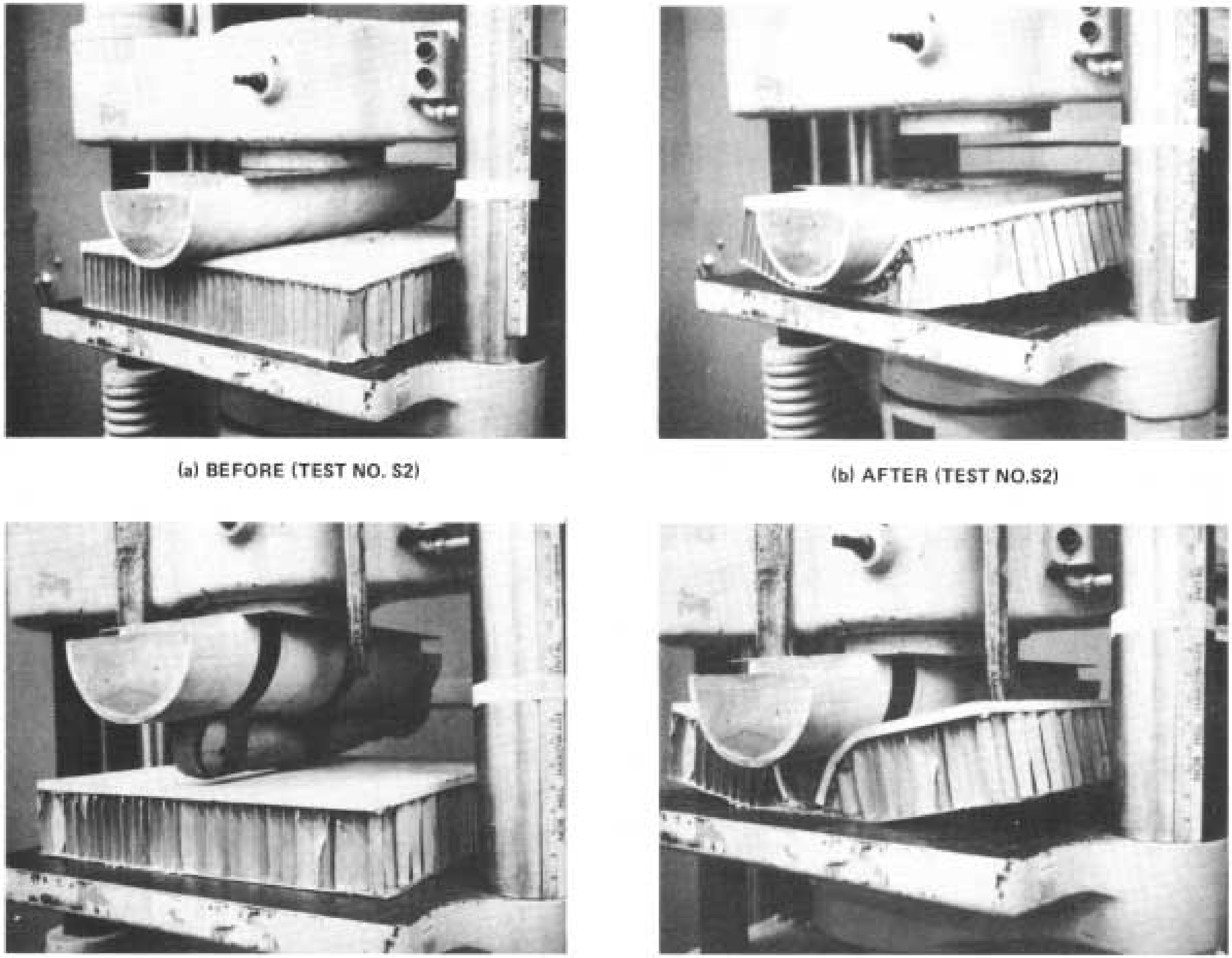
*INCLUDES COMPRESSION OF 1/2' ENSOLITE COVERING ON BODY FORM (ALSO COMPRESSION OF DUMMY ARM FOR TESTS S4 S7)

**THE SECOND DIMENSION IS PARALLEL WITH THE BODY FORM AXIS OF REVOLUTION possible that the arm of an occupant could be alongside the body, totally out of the contact zone, or somewhere in between. The test conditions represent the extreme cases, i.e., either totally constrained between the body and the contact surface or totally uninvolved.

The materials tested statically are briefly described in Table 6. Both flat and contoured surface panels were tested. Figure 15 illustrates the tests of flat paper honeycomb (4" thickness) panels covered by 1/2" of Ensolite. The static tests of the contoured door panels fabricated from 3/8" cell and 3/4" cell paper honeycomb and Ensolite material (see Figure 25) are shown in Figures 16 and 17 for the cases of the lateral body form with and without the dummy arm, respectively. Figure 18 shows the test of the 7.5 lb/ft.^{3} expanded urethane material.

Static test data are contained in Table 6 and Figure 19 for the various paper honeycomb door panel configurations. A large variation in crush strength is apparent between the paper honeycomb with different cell size. For the contoured panels, significant loads are not achieved until about 2 inches of crush due to the armrest projection, however, the increased overall depth of this configuration provides a greater total crush stroke. The contoured configuration containing the two types (different cell sizes) of honeycomb appears to have an overall crush strength more closely related to the 3/4" cell flat surface honeycomb configuration. The static test load-displacement curve for the expanded urethane material is included with the corresponding dynamic data (see Figure 23b).

Descriptions of the dynamic tests performed at nominal impact velocities of 10 and 20 MPH are contained in Table 7. The material compositions, dimensions and body forms were identical to the corresponding static test conditions. For the dynamic tests, the body forms and test specimens were installed on the Calspan linear accelerator test facility, as shown in Figure 20. The facility, in essence, is a small impact sled propelled by a



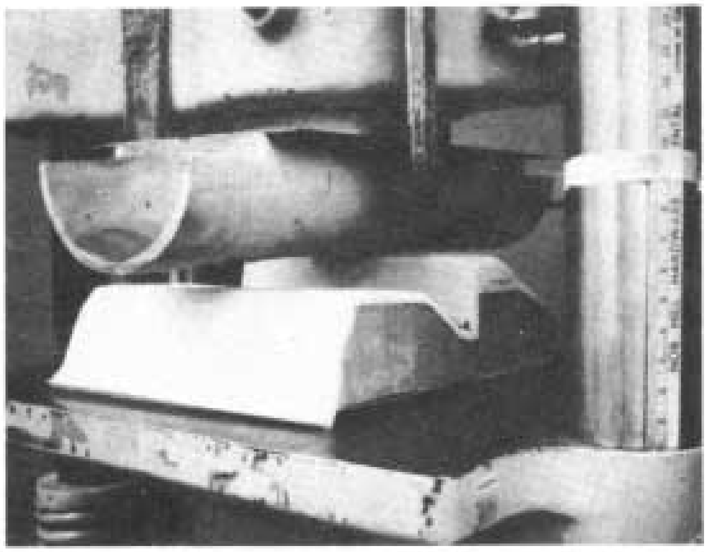
(a) BEFORE (TEST NO. S2)

(b) AFTER (TEST NO.S2)

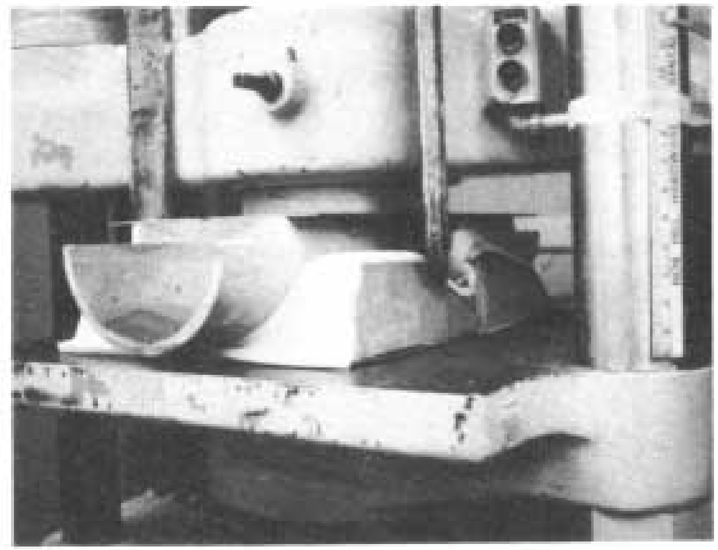
(c) BEFORE (TEST NO. S5)

(d) AFTER (TEST NO. S5)

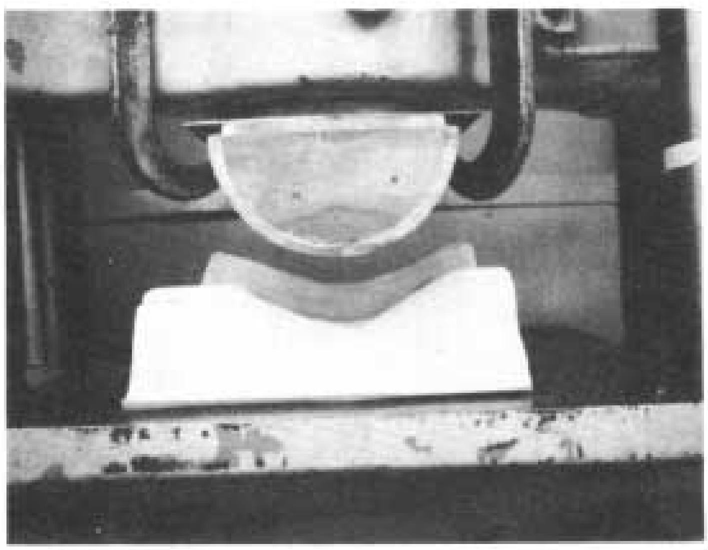
Figure 15 STATIC TESTS OF FLAT HONEYCOMB PANELS



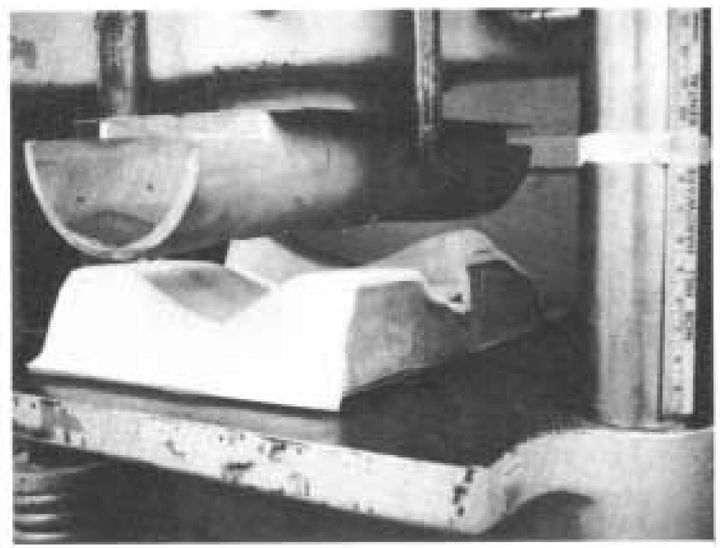
(a) BEFORE



(b) MAX. CRUSH

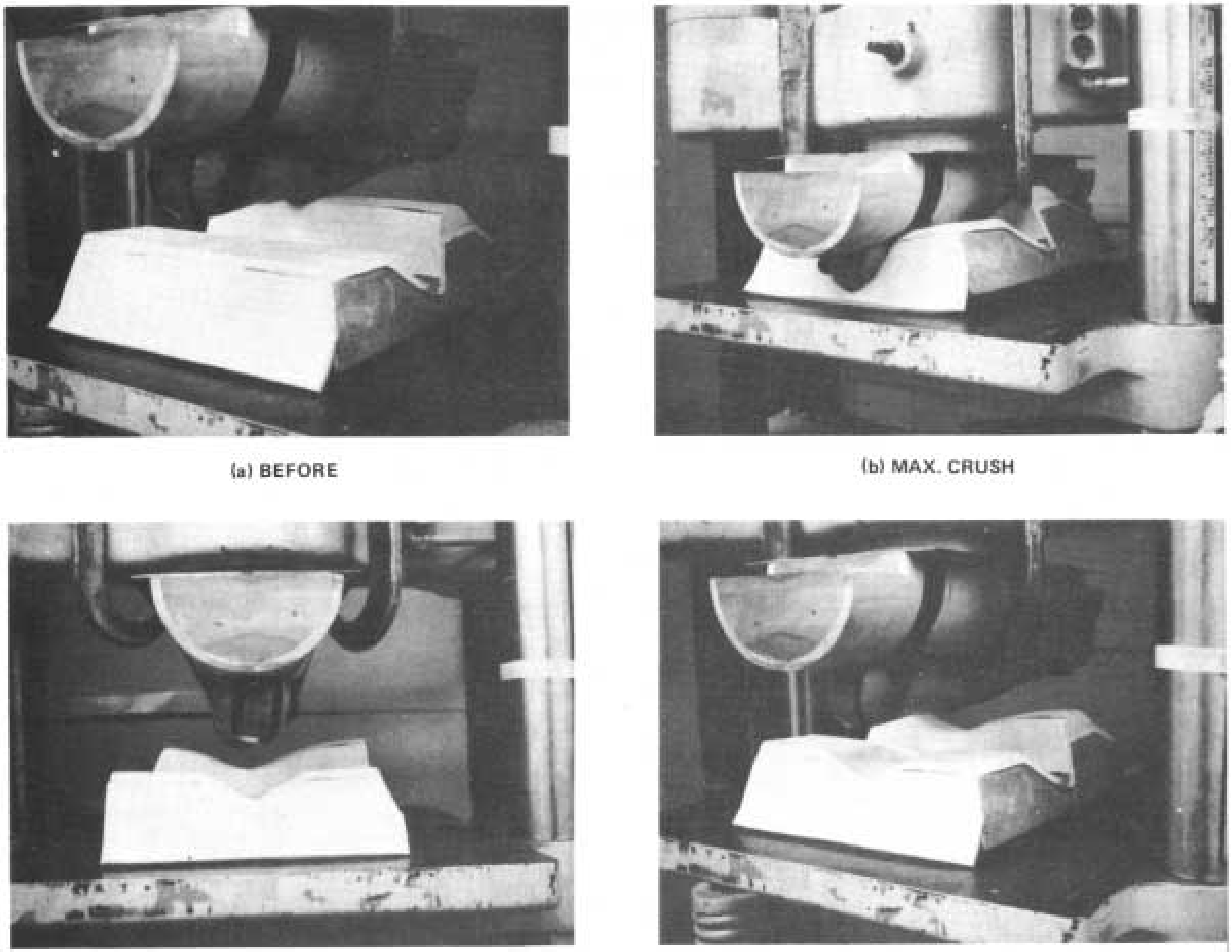


(c) AFTER



(d) AFTER

Figure 16 STATIC TEST OF CONTOURED PANEL WITH LATERAL BODY FORM (TEST NO. S3)



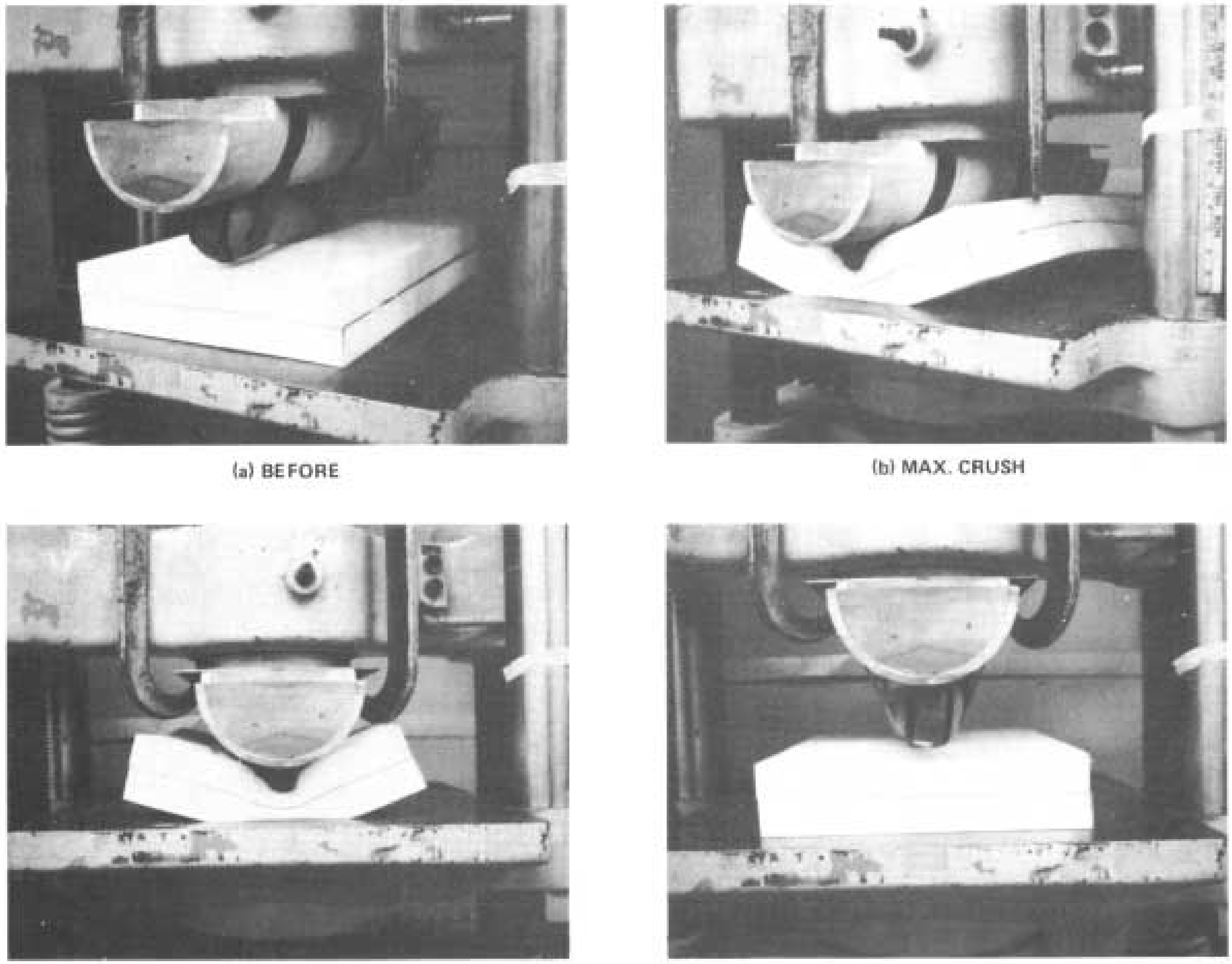
(a) BEFORE

(b) MAX. CRUSH

(c) AFTER

(d) AFTER

Figure 17 STATIC TEST OF CONTOURED PANEL WITH DUMMY ARM (TEST NO. S6)



(a) BEFORE

(b) MAX. CRUSH

(c) MAX. CRUSH

(d) AFTER

Figure 18 STATIC TEST OF EXPANDED URETHANE (TEST NO. S7)

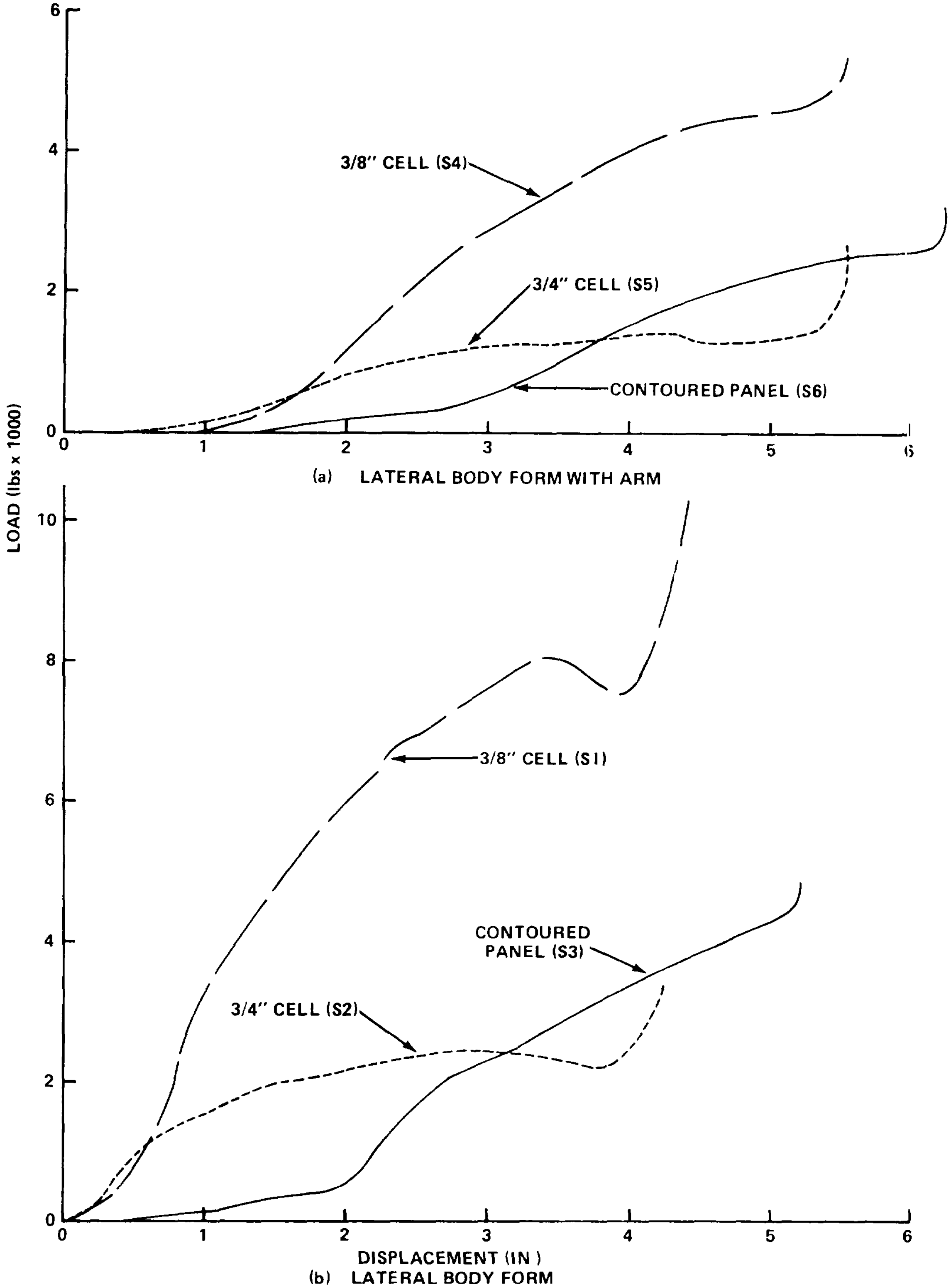


Figure 19 STATIC LOAD-DISPLACEMENT CHARACTERISTICS OF HONEYCOMB PANELS

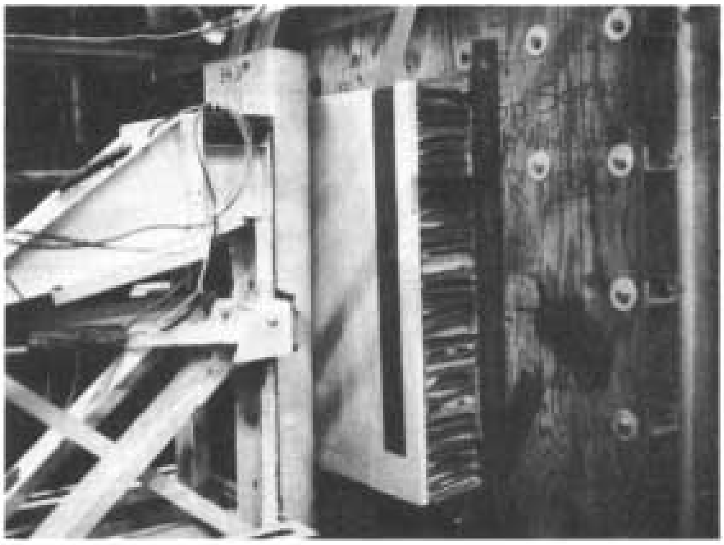
Table 7

DYNAMIC TESTS OF PADDING MATERIALS

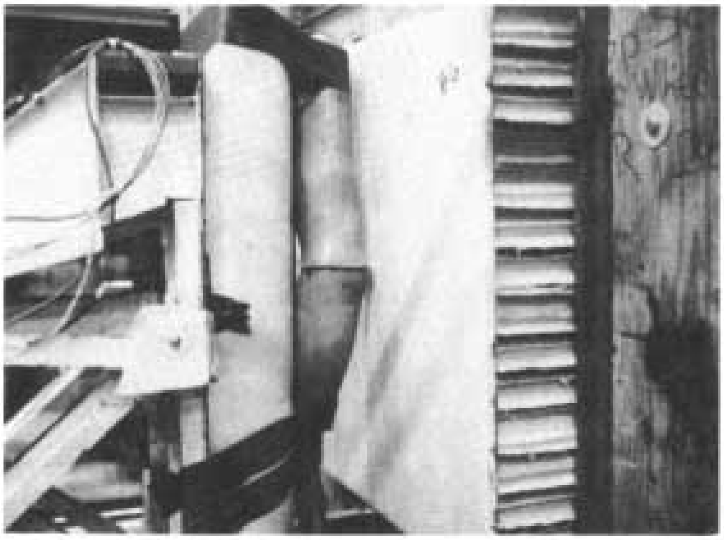
TEST NO	IMPACT VELOCITY (MPH)	BODY FORM	MATERIAL	MAX CRUSH* (IN.)	MAX.LOAD** (LBS)
D1	10.0	LATERAL (93 LBS)	½" ENSOLITE OVER 4" PAPER HONEYCOMB (3/4" CELL)	2.1	2800
D2	18.9	LATERAL	½" ENSOLITE OVER 4" PAPER HONEYCOMB (3/4" CELL)	3.7	3500
D3	9.5	LATERAL	4" S-00230 EXPANDED URETHANE	1.1	6400
D4	19.7	LATERAL	4" S-00230 EXPANDED URETHANE	1.9	12000
D5	10.0	LATERAL/ARM (102 LBS)	½" ENSOLITE OVER 4" PAPER HONEYCOMB (3/4" CELL)	4.0	2100
D6	20.3	LATERAL/ARM	½" ENSOLITE OVER 4" PAPER HONEYCOMB (3/4" CELL)	5.0	3600
D7	10.5	LATERAL/ARM	4" S-00230 EXPANDED URETHANE	2.5	4400
D8	22.4	LATERAL/ARM	4" S-00230 EXPANDED URETHANE	3.7	9700

* INCLUDES COMPRESSION OF ½" ENSOLITE COVERING ON BODY FORM (ALSO COMPRESSION OF DUMMY ARM FOR TESTS D5-D8)

** BEFORE BOTTOMING OCCURS IN TESTS D2 AND D6.



(a) LATERAL BODY BLOCK



(b) WITH DUMMY ARM ATTACHED

Figure 20 LINEAR ACCELERATOR TEST SETUP

hydraulic cylinder capable of accelerating a 100 lb mass up to 40 MPH in a stroke of 12.9 inches. The impact speed is regulated by the initial pressure of the silicone base hydraulic fluid The movable cart with the body form attached is brought to rest by the impact with the material test specimen and a rebound arresting device.

Load-displacement results for the flat honeycomb panels are presented in Figure 21 along with the corresponding static test data It is noted that, for a given displacement, the dynamic loads generally exceeded the static levels, indicating some rate sensitivity. This effect appears to be more significant for the case where the dummy arm was included with the body form The reason for this is not clear but it is hypothesized that variation of the crush strength properties between the various test specimens could account for this behavior,* possible rate sensitivity of the dummy skin material could also have caused this effect In any event, the dynamic loads generally exceeded the static loads by nominal values of from 20 to 100%, but more testing and analysis would be required to determine the exact cause of this apparent rate sensitivity The deformation of the honeycomb panels resulting from each test is shown in Figure 22

Dynamic test results contained in Figure 23 for the expanded urethane material indicate that this material possesses dramatic rate sensitivity Note particularly the comparison with static test results in Figure 23(b) This behavior reflects the highly viscoelastic nature of the particular urethane material, i.e , the material tends to relax or flow under slowly applied loading but, as is characteristic of viscous materials, exhibits increased flow resistance as the displacement rate increases Recovery of the material to its original shape takes place following impact as a result of its elastic properties

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* See discussion of paper honeycomb crush strength variability on page 61

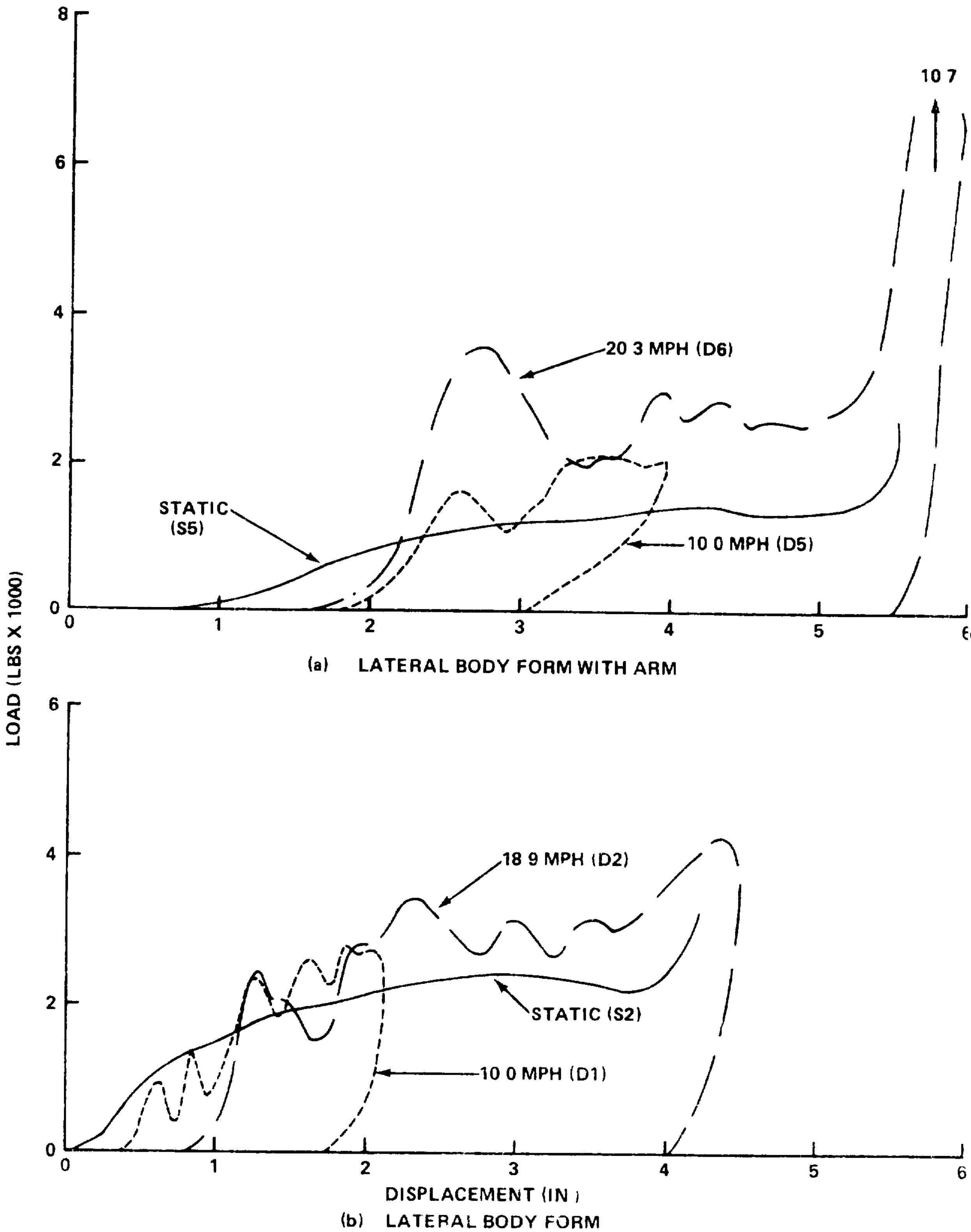
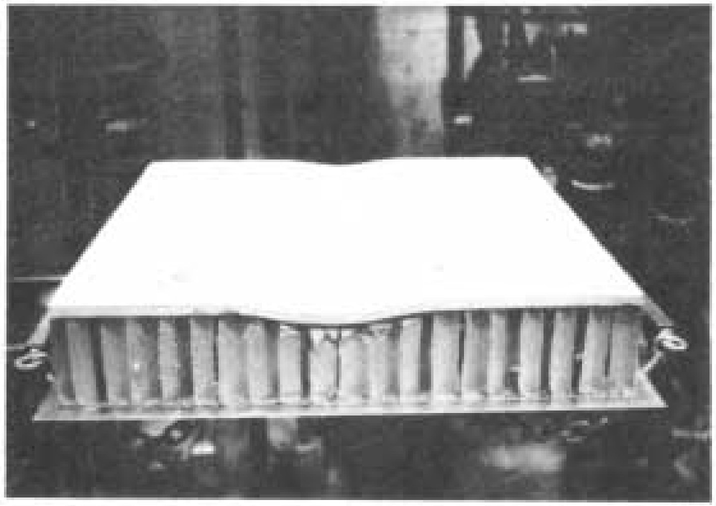
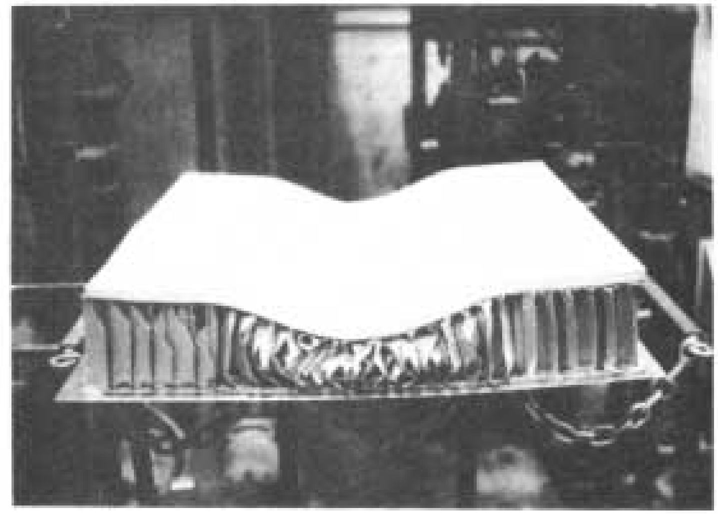


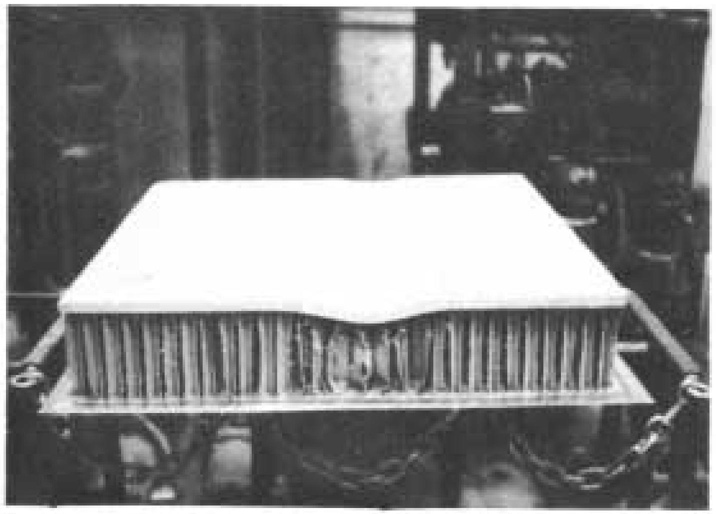
Figure 21 LOAD DISPLACEMENT CHARACTERISTICS OF FLAT HONEYCOMB PANELS (3/4" CELL)



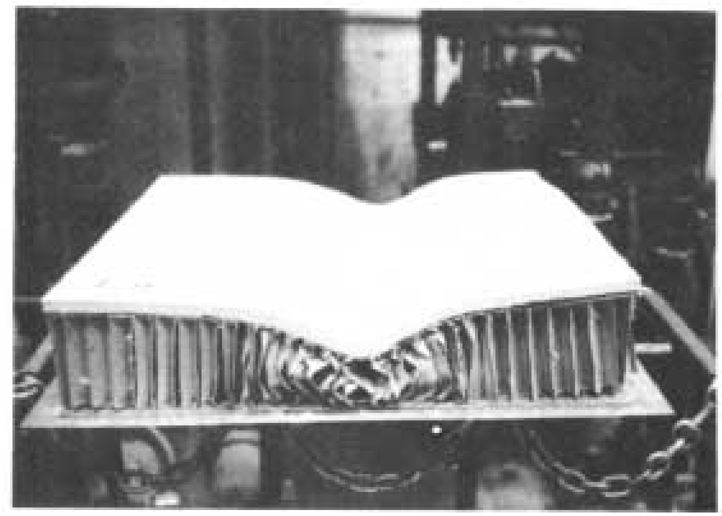
(a) WITHOUT ARM, 10.0 MPH



(b) WITHOUT ARM, 18.9 MPH



(c) WITH ARM, 10.0 MPH



(d) WITH ARM, 20.3 MPH

Figure 22 DYNAMIC CRUSH OF HONEYCOMB DOOR PANELS

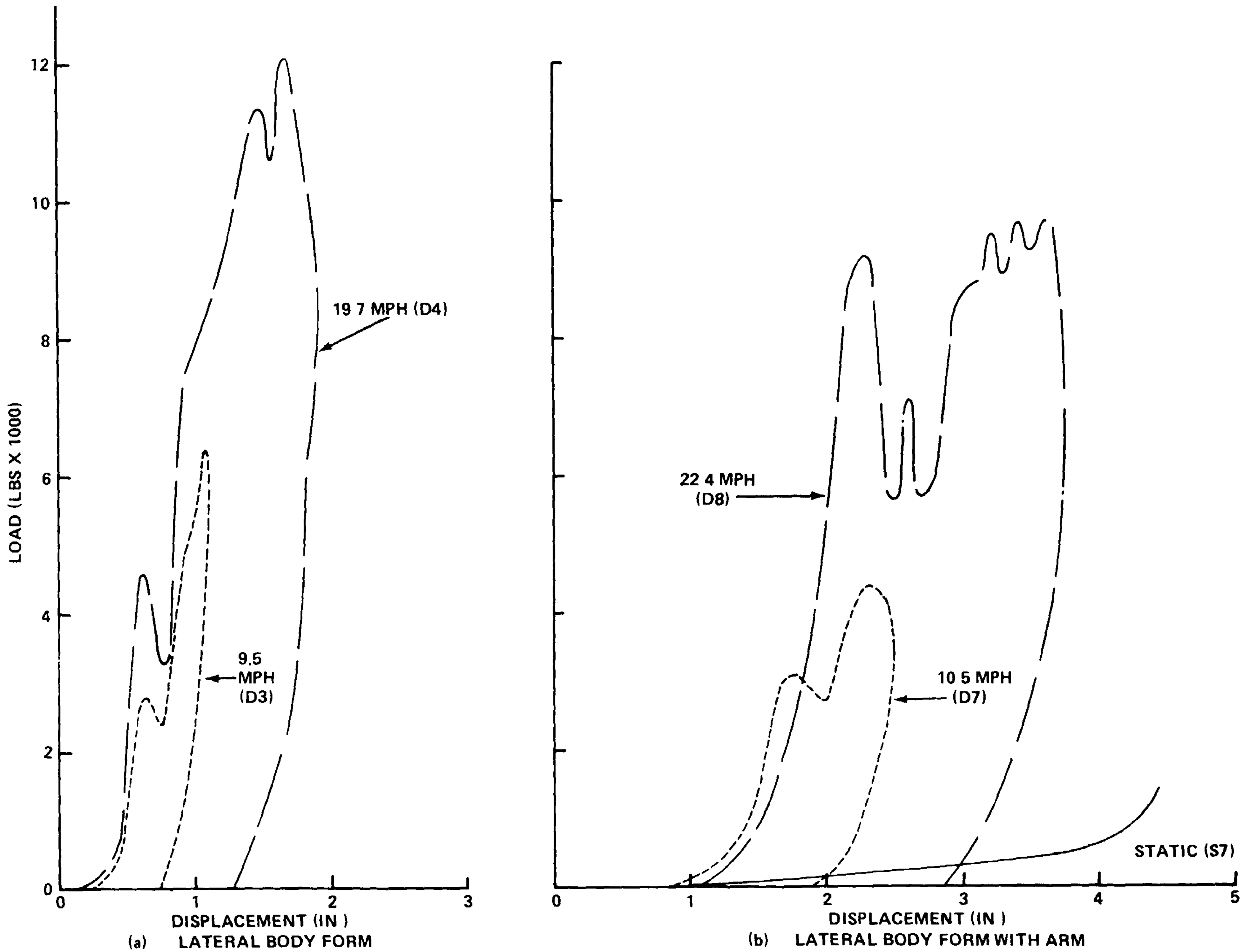


Figure 23 LOAD-DISPLACEMENT CHARACTERISTICS OF EXPANDED URETHANE

4.3.2 Modified Vehicle Interior Installation

Figure 24 illustrates the areas of the interior sidewall that were modified for increased occupant protection. Also shown are the positions of Part 572 dummies with respect to the padded areas. It should be noted that the upper B-pillar, although a likely target for occupant contact in certain lateral impact situations, is not shown as a padded area because the structural pillar modification was not fabricated to represent a reasonable pillar cross-section shape.*

Reference 3 describes the various padding concepts and certain lateral impact test data which characterize the padding performance. For example, results of a 30 MPH perpendicular impact by a contoured-surface moving barrier indicated the following peak head, chest, and pelvic loadings for 50th percentile dummies located on the struck side of the modified vehicle:

	Front Dummy	Rear Dummy
Head Severity Index	181	160
Head Resultant Acceleration	44 g's	40 g's
Chest Resultant Acceleration	45 g's	37 g's
Pelvis Resultant Acceleration	46 g's	23 g's

No evidence of bottoming out of the padding materials was observed. Extrapolating to the lateral impact test conditions specified for this program, it was concluded that the same basic interior design would likely be capable of demonstrating the required occupant protection. Although some minor design

* Due to funding limitations, fabrication of a die formed prototype B-pillar was not possible (this was done in Contract DOT-HS-053-2-487). Instead, the B-pillar was constructed from rectangular steel tubing with similar strength characteristics.

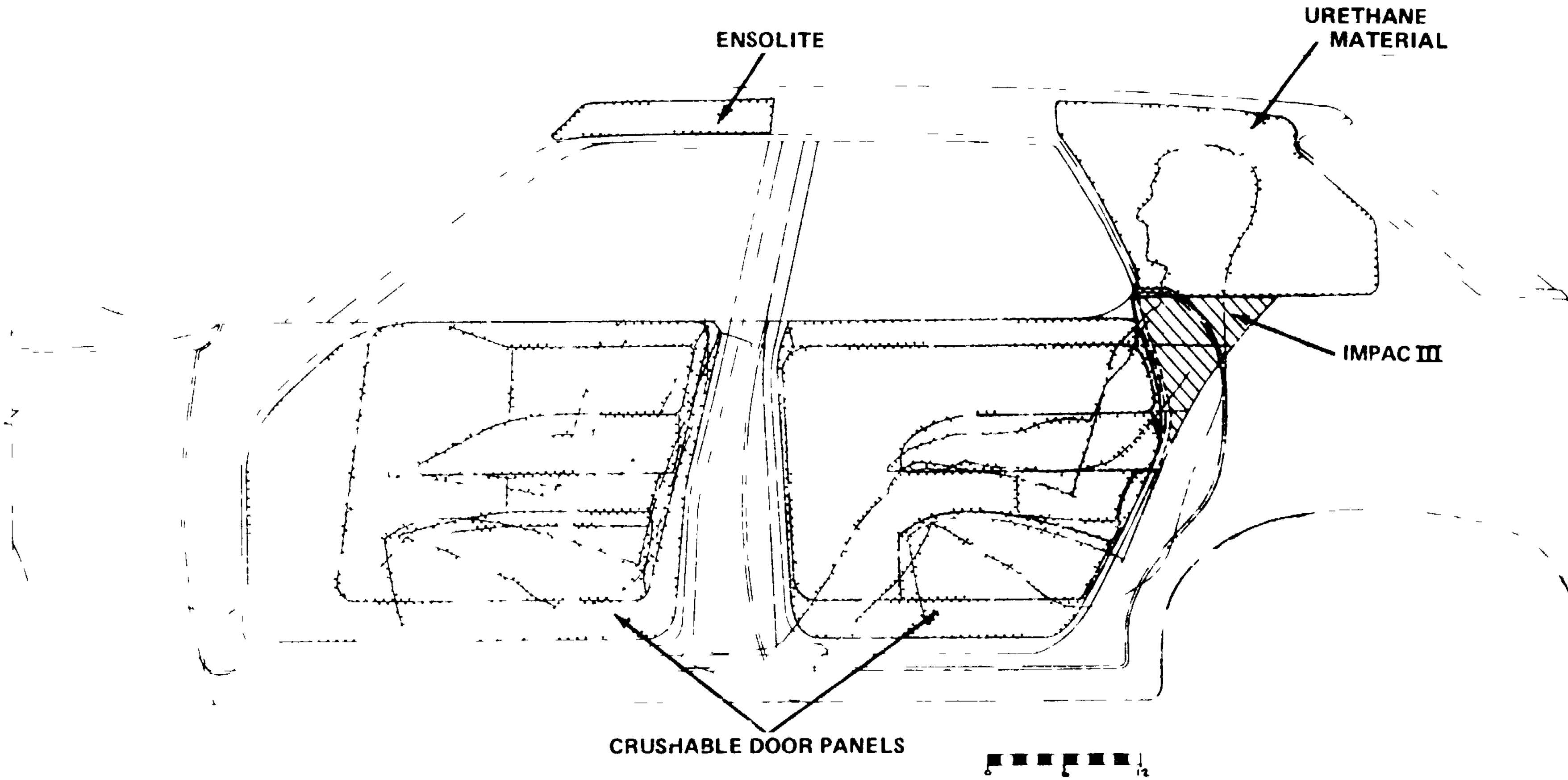


Figure 24 INTERIOR PADDING MODIFICATIONS

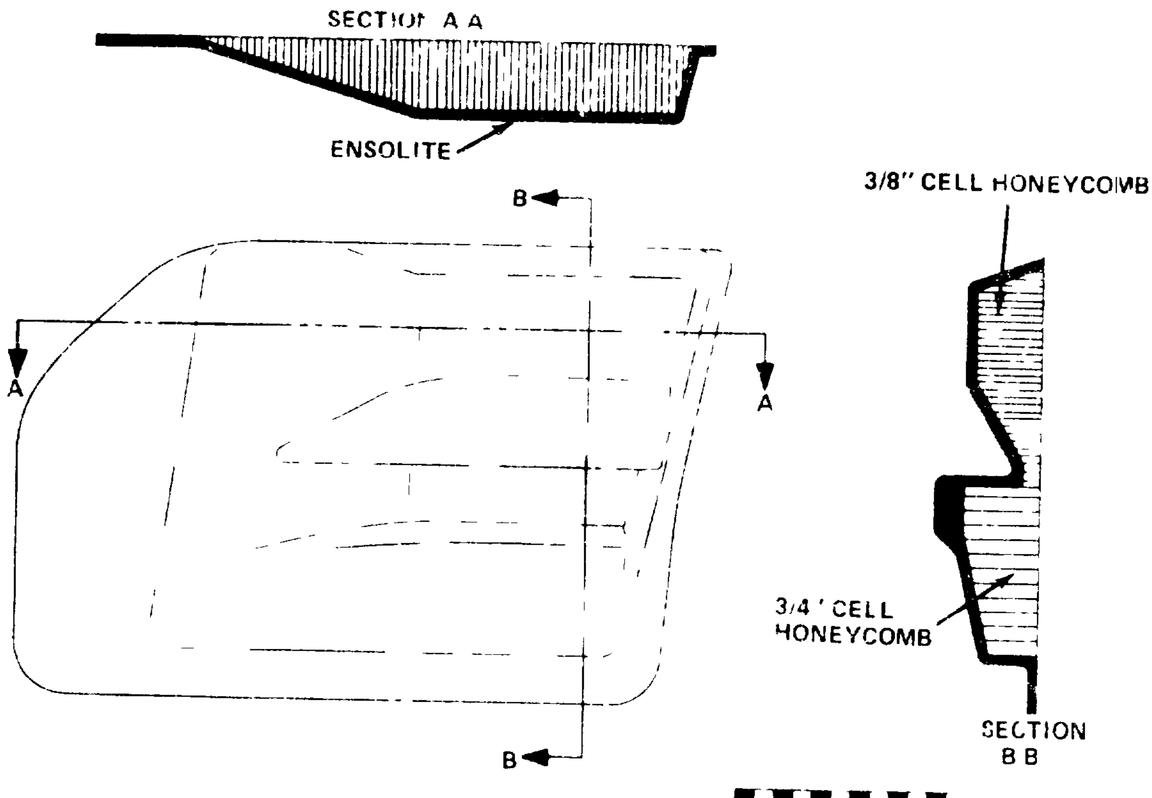
changes were made during the course of the crash testing, the basic design was generally maintained throughout

Additional descriptions of the various padding materials and constructions are given below·

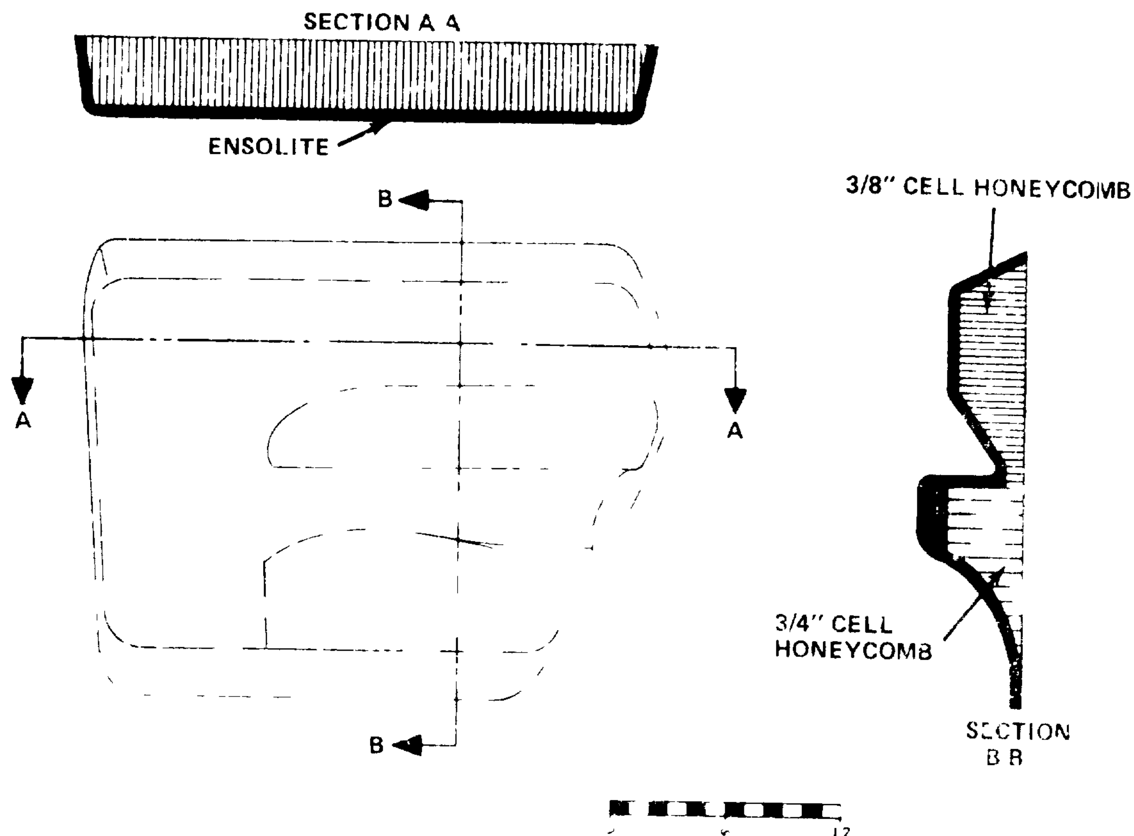
- Crushable Door Panels

Designs of the front and rear door panels are illustrated in Figure 25 As noted, the panels were constructed from both 3/8" cell and 3/4" cell paper honeycomb with a covering of Ensolite material. The use of the different cell size honeycomb on the upper and lower surfaces was necessary to more evenly distribute the chest and pelvic loadings due to the variation of contact areas (hip contact area is larger than the contact area of the upper torso). The paper honeycomb materials were bonded to flat .040" aluminum sheets with Hysol Type 3X adhesive. The aluminum panels, which provided a means of attachment to the conventional inner door panels, contained a matrix of 3/8" holes to allow air to be partially expelled from the honeycomb cells during the crush stroke. The Ensolite covering was bonded to the shaped paper honeycomb using 3M No 847 industrial adhesive, this covering provides a resilient surface that would prevent damage to the honeycomb in very low speed impacts and from normal vehicle usage

Material compositions and properties are given below.



(a) FRONT DOOR PANEL



(b) REAR DOOR PANEL

Figure 25 DESIGN OF CRUSHABLE DOOR PANELS

3/8" cell paper honeycomb (non-impregnated)*

Type KP 3/8 - 80(0)E

Density = 2.1 lbs/ft^3 (expanded)

Paper weight = 80 lbs/ream

Nominal compressive strength = 72 psi

Nominal crush strength = 36 psi

3/4" cell paper honeycomb (non-impregnated)*

Type KP 3/4 - 80(0)E

Density = 1.2 lbs/ft^3 (expanded)

Paper weight = 80 lbs/ream

Nominal compression strength = 39 psi

Nominal crush strength = 20 psi

Ensolite**

Expanded, closed cell, modified polyvinyl chloride

Type AL

Density $\cong$ 7 lbs/ft^3 (expanded)

25% compressive strength $\cong$ 5 psi

Technical representatives of Hexcel Corporation have indicated that there are basic limitations of paper honeycomb that are pertinent to automotive energy-absorption applications (Ref. 9). The possible deficiencies include (a) production tolerances are such that variations of crush strength

* Procured from Hexcel Corporation

** Procured from local vendor (a Uniroyal product) up to $\pm$ 20% of the nominal value can be expected, (b) prolonged high humidity exposure can reduce the crush strength by as much as 50%, (c) water absorption causes paper deterioration, and (d) flammability. Impregnation with phenolic resins can provide protection against humidity and moisture absorption. However, it is not presently known how well impregnated paper would withstand these conditions throughout the service life of an automobile. Treatment with flame-retardant chemicals is also possible to reduce combustibility

In summary, paper honeycomb materials are known to possess exceptional energy absorption characteristics, are lightweight and are presently being produced in large volumes.* However, it has not yet been established whether or not these materials are suitable for automobile applications in view of the uncertainties pointed out above. Further study is needed to resolve the feasibility question and to establish production cost estimates for crushable door panel designs.

- Upper C-pillar Area

The material used for head protection in this area was a 7.5 lb/ft^3 open celled, polyether urethane denoted as Type S-00230 by the supplier.** This material has pronounced viscoelastic characteristics as indicated by its

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* Aluminum honeycomb with the desired crush strength is, to our knowledge, not commercially available and these materials are much more expensive than paper honeycomb products.

** Procured from Specialty Composites Corporation, Newark, Delaware. This is an experimental material currently under development and is not believed to be commercially available at this time.

ability to efficiently dissipate kinetic energy (high hysteresis loss) and full recovery to its original shape after impact.

Reference 2 contains results of headform testing which show that effective head protection can be achieved using a 2" thickness of this material (as installed in the C-pillar area) up to impact speeds in the neighborhood of 12 to 15 MPH at room temperature, based on a maximum 80 g requirement.* As is the case for all urethane base materials, a possible deficiency is its significant sensitivity to temperature, i.e., the compressive strength decreases as temperature increases, and vice versa. Consequently, the impact protection properties are degraded under conditions of high and low temperatures, as is presently the case with energy absorbing dashpanels containing urethane padding. However, normal compartment heating and cooling would be expected to alleviate this problem to some extent.

Static load-deflection data presented in Section 4.3.1 for a lateral body form loading configuration showed that the Type S-00230 urethane material is highly rate sensitive. This behavior is believed to be generally advantageous in this application where the material thickness is severely limited by the dimensional constraints of the passenger compartment. That is, peak head loading will vary as a function

* The human tolerance criterion relating to head impact assumed for this investigation (HIC < 1000) appears to be less stringent, indicating acceptable performance at velocities approaching 20 MPH.

of impact velocity such that complete material compression (bottoming out) is avoided. In any event, crash test results contained in Section 5 demonstrate that adequate head protection for the rear occupant (dummy) was achieved under all the lateral impact test conditions investigated.

- Mid C-pillar Area

The design of the 1973 Ford is such that a triangular shaped sidewall area exists behind the rear door structure, adjacent to the upper torso of a rear occupant. A crushable padding utilizing paper honeycomb material, such as was used for the door panels, cannot be employed in this limited size area because edge effects predominate, i e , the cells of the paper honeycomb do not collapse in a controlled manner but tend to 'blow out" toward the edges. As a result, an expanded urethane material with a nominal thickness of 4 inches was selected for this area Based on a previous material testing (References 2 and 3), Scott Paper Co Impac III material, a semi-flexible, open cell polyether foam with a density of approximately 3 lb/ft^3, appeared to be well suited for this application

For one crash test (No 12), the same urethane used in the upper C-pillar area (described above) was substituted for the Impac III in order to evaluate the effect of increasing the compression strength of the padding material used in this area.

- Roof Side Header

Achieving effective head impact protection in this area is extremely difficult due to the dimensional constraint and structural requirements of the roof header In fact, a more reasonable approach might be to design the passenger compartment geometry and/or restraint system such that head contact in this area could be avoided. Nevertheless, an attempt was made to offer a limited amount of head protection in this area by applying a layer of 1/2" Ensolite over the header structure and behind the molding strip. An extensive investigation of energy absorption concepts (e.g., thin-walled metal collapsible structures) would probably be necessary in order to design more effective head protection features into the roof header structure.*

Figure 26 shows examples of the various interior modifications Approximate weights of the modifications are given below.

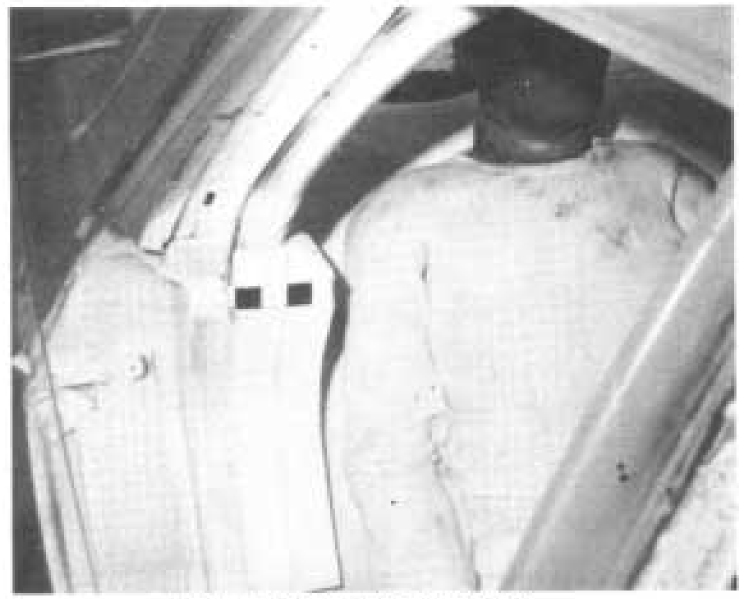
Component	Weight (lbs)
Crushable front door panel	8 5
Crushable rear door panel	10.0
Upper C-pillar padding	2.5
Mid C-pillar padding (Impac III material)	0 5
	21.5 x 2 = 43.0 (both sides)

* This discussion is also applicable to the problem of side pillar head impact protection (A- and B-pillars for the 1973 Ford automobile).

(a) FRONT DOOR PANEL

(b) REAR DOOR PANEL

(c) UPPER C-PILLAR PADDING



(d) MID C-PILLAR PADDING

Figure 26 EXAMPLES OF INTERIOR MODIFICATIONS

A total of five modified vehicles were crash tested (see Section 5). The following table indicates the combination of structural, glazing (see Section 4.2.2) and interior modifications contained in each vehicle:

Modified Vehicle Designation	Structure	Glazing	Interior
A	X	X	X*
B	X	X	-
C	X	X	X
D	X	X	X**
E	-	X	X

* This vehicle was subjected to two crash tests; interior modifications were made to the left side only (for Test No. 11).

** Mid C-pillar padding changed from Impac III to S-00230 urethane for Test No. 12.

5. MODIFIED VEHICLE TESTING

Table 8 lists the modified vehicle tests that were performed. Test conditions generally corresponded either to Configuration No. 3 or No. 5 (see Section 2.1). The target impact speed of 39.0 MPH was selected for the Configuration No. 5 tests* because the corresponding baseline test was somewhat under the intended velocity (see Table 1), the chosen target speed is between the actual baseline velocity (37.3 MPH) and the intended impact speed (40.0 MPH). For all modified vehicle tests, the actual impact speeds were extremely close to the target velocities.

Consistent with the baseline tests (see Section 3), all striking vehicles were 1973 Ford 4-door automobiles with the bumper reinforcement structures replaced by the strengthened 1974 Ford assemblies. Test No. 11 employed the same moving barrier test device as was used for Test No. 6 of the baseline series. Striking vehicle test weights were approximately equal to the corresponding baseline test weights. Modified struck vehicle test weights were generally comparable to the baseline struck vehicle test weights because the removal of various vehicle components required during the structural fabrication procedure tended to balance out the additional weight of the structural modifications.

The general nature of the struck vehicle modifications is indicated in Table 8 for each test. More detailed information regarding the specific glazing and interior modifications can be found by referring to page 46 (glazing description) and page 67 (interior description) and correlating the letter-designated vehicles to the specific tests as given below. The associated baseline tests are also indicated in the following table.

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* Except for Test No. 12 for which a higher impact speed was selected.

Table 8
MODIFIED VEHICLE TESTS

TEST NO	CONFIGURATION NO *	IMPACT SPEED (MPH)		VEHICLE TEST WEIGHT (LBS)		STRUCK VEHICLE MODIFICATIONS
		TARGET	ACTUAL	STRIKING	STRUCK	
8	5	39 0	39 1	4530	4620	STRUCTURE & GLAZING
9	5	39 0	39.1	4485	4780	STRUCTURE, GLAZING & INTERIOR
10	3	30.0	29.8	4500	4740	STRUCTURE & GLAZING
11	3**	30.0	30.2	4050	4740	STRUCTURE, GLAZING & INTERIOR
12	5	50.0***	50.5	4520	4740	STRUCTURE, GLAZING & INTERIOR
N-1****	5	39.0	39.2	4490	4820	GLAZING & INTERIOR

*DEFINED IN SECTION 2.1
**MOVING BARRIER USED AS STRIKING VEHICLE
***IMPACT SPEED INCREASED
****PARTIALLY FUNDED BY NAFEC UNDER PURCHASE ORDER NO. NA-~~P~~5-2213

Modified Vehicle Test No.	Modified Vehicle Designation	Corresponding Baseline Test No.
8	B	5
9	C	5
10	A	3
11	A	6
12	D	-
N-1	E	5

Except for Vehicle E, which contained glazing and interior modifications only, all struck vehicles contained similar structural modifications.* As previously noted, Test No. 12 was performed according to the Configuration No. 5 geometry but at a higher impact speed, a comparative baseline test therefore does not exist for this case.

The modified vehicle test matrix was defined such that all four combinations of conventional and modified structural and interior configurations could be evaluated for the nominal 40 MPH perpendicular collision case (Configuration No. 5). This is illustrated below where the specific test numbers are provided.

	Conv. Interior	Mod. Interior
Conv. Structure	5 (baseline)	N-1
Mod. Structure	8	9

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* Complete structural modifications were generally restricted to the struck side, i.e., the side opposite impact did not contain modified side pillars and door beams. An exception was Vehicle A, which was fully modified on both sides and subjected to two lateral impacts (one on each side).

Results of Test No. 10 enable evaluation of the structural performance for the 30 MPH oblique impact case (Configuration No. 3) and Test No. 11 provides related data for the case where both structural and interior modifications are included and a contoured-surface moving barrier is employed as the striking vehicle. Test No. 12 was performed to better define the upper limit of protection offered by the combined structural and interior modifications for the perpendicular impact configuration. It should be recalled that supported, laminated side glazing was installed in all of the modified vehicles.

Appendix B contains complete test descriptions and data for each of the modified vehicle crash tests, including the following information:

- description of test conditions
- post-test observations
- vehicle and dummy photographs
- vehicle exterior deformation profiles
- passenger compartment static intrusion measurements
- vehicle acceleration responses and integrated velocity and displacement time histories
- Part 572 dummy (in struck vehicle) acceleration responses, integrated velocity and displacement time histories, head and chest severity indices and HIC numbers

Table 9 summarizes test results which characterize the structural and glazing performance of the modified vehicles. These results, however, reflect an extremely limited sampling of the available test information and the reader should consult Appendix B for a more complete understanding of the structural and glazing performance It is important to point out that the glazing fracture indicated in Table 9 was invariably caused by structural deformation and/or impact shock and not by dummy contact Furthermore, the front door laminated glazing, although the glass plies were fractured, remained in place in each case as a result of the constraint provided by the peripheral support structures and the plastic layer of the laminates

A summary of anthropomorphic dummy data is presented in Table 10 Information is given pertaining to dummy containment within the passenger compartment, region of head contact (if applicable), relative velocity of head contact (based on film analysis), and the peak acceleration responses and associated injury indicators Peak acceleration responses which exceeded the assumed injury criteria are denoted.

The Hamilton Rolamite (Serial No 2164) crash sensor mounted on the firewall of the struck vehicle (oriented longitudinally) triggered in two instances Activation signals were observed in Test No 1 at 13 msec and in Test No 12 at 20 msec. after initial contact. Acceleration data were obtained from transducers mounted to the same fixture as the crash sensor (data contained in Appendix B) The acceleration pulse to which the crash sensor was subjected can therefore be correlated with the sensor response

Table 9

SUMMARY OF STRUCTURAL AND GLAZING PERFORMANCE

TEST NO.	MAXIMUM STATIC CRUSH (in)		STRUCK VEHICLE STATIC INTRUSION (in.)			STRUCK VEHICLE LATERAL ACCELERATION (g)**		TIME OF GLAZING FRACTURE (msec)	
	STRIKING	STRUCK	FRONT DOOR*	REAR DOOR*	MAX.	AVERAGE	PEAK	FRONT DOOR***	REAR DOOR
8	15.0	14.5	3.8	7.5	8.7	14.1	30.4	10	28
9	12.0	15.2	4.5	5.1	8.0	15.1	21.7	21	35
10	13.0	14.0	4.1	2.9	6.5	4.4	13.2	38	–
11	0	15.5	7.4	1.9	7.4	8.1	20.4	13	–
12	27.5	19.0	7.8	9.0	12.4	9.6	42.0	13	14
N-1	11.2	24.0	7.3	9.5	12.8	6.2	32.8	13	37

* CENTERLINE OF DOOR AT MID LEVEL

** DETERMINED FROM ACCELEROMETER MOUNTED ON FLOOR PAN TUNNEL BEHIND FRONT SEAT (PEAK VALUES BASED ON A 3 msec CLIP)

*** SUPPORTED, LAMINATED GLASS RETAINED IN PLACE

Table 10

SUMMARY OF ANTHROPOMORPHIC DUMMY DATA FOR MODIFIED VEHICLE LATERAL COLLISION TESTS

PARAMETER		INJURY CRITERIA*	DUMMY IN FRONT SEAT: TEST NO 8	TEST NO 9	TEST NO 10	TEST NO 11	TEST NO 12	TEST NO N 1
CONTAINMENT OF DUMMY			YES	YES	YES	YES	YES	YES
HEAD RESPONSE	PRIMARY CONTACT LOCATION	–	ROOF SIDE HEADER & UPPER GLASS EDGE	NONE	ROOF SIDE HEADER	WINDSHIELD HEADER	NONE	CEILING
	TIME OF CONTACT * (msec)	–	45	—	92	153		125
	CONTACT VELOCITY** (mph)	—	13 3	—	7 8	N/A		N/A
	HIC NUMBER	1000	306	79	46	101	170	296
	A P ACC (g)		9	4	9	0	6	
	L R ACC (g)		52	18	18	31	30	65
	S I ACC (g)		28	18	23	22	[illegible]	34
	RESULT ACC (g)		58	25	30	34	46	2
CHEST RESPONSE	A P ACC (g)	60	11	10	5	8	12	8
	L R ACC (g)	45	$\boxed{73}$	30	30	44	$\boxed{75}$	$\boxed{53}$
	S I ACC (g)	20	7	6	6	7	13	15
	RESULT ACC (g)	60	$\boxed{73}$	30	30	44	$\boxed{76}$	54
PELVIC RESPONSE	L R ACC (g)		55	50	25	59	108	74

PARAMETER		INJURY CRITERIA	DUMMY IN REAR SEAT: TEST NO 8	TEST NO 9	TEST NO 10	TEST NO 11	TEST NO 12	TEST NO N 1
CONTAINMENT OF DUMMY			YES	YES	YES	YES	YES	[illegible]
HEAD RESPONSE	PRIMARY CONTACT LOCATION		C PILLAR	C PILLAR PADDING	C PILLAR	PILLAR PADDING	C PILLAR PADDING	C PILLAR PADDING & REAR HEADER
	TIME OF CONTACT		5	57	93	60	56	62 116
	CONTACT VELOCITY		14 9	14 8	11 3	13 4	15 6	1 6/NA
	HIC NUMBER	[illegible]	733	96	474	217	263	675
	A P ACC (g)		8	8	21	18	4	
	L R ACC		109	37	83	53	49	76
	S I ACC		46	30	45	8	26	38
	RESULT ACC (g)		10	39	86	57	52	80
CHEST RESPONSE	A P ACC	[illegible]	14	5	15	6	18	3
	L R ACC	[illegible]	$\boxed{96}$	$\boxed{52}$	$\boxed{62}$	30	$\boxed{70}$	
			8	7	6	8	18	13
	RESULT ACC		$\boxed{96}$	52	$\boxed{62}$	32	$\boxed{71}$	68
PELVIC RESPONSE	L R ACC		59	39	14	21	104	[illegible]

*AS SPECIFIED IN WORK STATEMENT
OBTAINED FROM FILM ANALYSIS
DOES NOT RESULT FROM CONTACT WITH VEHICLE STRUCTURE
N A CANNOT BE ACCURATELY DETERMINED FROM PHOTOGRAPHIC COVERAGE

NOT [illegible] TION MAX MA ARE EXCEEDED ONLY [illegible] TIME INTER A NO GREATER THAN [illegible] SECONDS

6. DISCUSSION OF RESULTS

Results of the baseline and modified vehicle crash tests are discussed in this section.

6.1 Baseline Tests

Two of the baseline test configurations were designed to simulate lateral impact cases where both the striking and struck vehicles are initially in forward motion (see Section 2.1). The method of simulating this impact condition appears to be practical, easily repeatable and realistic with respect to the particular test procedure, collision mechanics and primary occupant responses. Obviously, the post-impact struck vehicle trajectories and secondary occupant motions are not well simulated due to the unrealistic ground/tire forces generated by the directional reversal and variant wheel rotational velocities introduced by the nature of the test method. Nevertheless, the simulation method is well suited to the investigation of primary impact occupant survivability, which was the focus of this study

Crash Tests No. 1 and 2 simulated perpendicular lateral collisions in which the striking vehicles were traveling at a nominal speed of 30 MPH at impact. The difference between the tests was the simulated initial forward speed of the struck vehicles, Test No. 2 represented the case where the struck vehicle was traveling at 30 MPH at impact while, for Test No. 1, the struck vehicle was assumed to be initially stationary. Comparing these two tests indicates the effect of the tangential velocity* between the vehicles on the struck vehicle structural performance and occupant responses.

* Defined as the simulated forward velocity of the struck vehicle at impact

Figure 27 compares the vehicle deformation for these two cases. As would be expected, the tangential velocity tends to extend the struck vehicle damage rearward. Front door intrusion was lower for Test No. 2 and approximately the same for the rear door (see Table 2). Acceptable structural integrity was maintained for both cases. Occupant responses presented in Table 3 indicate that the acceleration exposure of the front seat dummy was more severe in Test No. 1 (zero tangential velocity) than for Test No. 2 (30 MPH tangential velocity), whereas the opposite trend is evident for the rear seat dummy. For both cases, the front seat dummy responses were well within the assumed human tolerance limits. The lateral chest acceleration of the rear dummy was marginal for Test No. 1 and exceeded the particular injury criterion for Test No. 2.

A corresponding evaluation of the effect of tangential velocity in oblique* lateral collisions can be made by comparing results of Tests No. 3 and 4. In both cases, the striking vehicle was traveling at a nominal forward speed of 30 MPH at impact. Test No. 4 represented the case where the struck vehicle was simulated to be in forward motion at 30 MPH, whereas the struck vehicle was assumed to be initially stationary for Test No. 3.

Figure 28 shows that the struck vehicle deformation was mainly restricted to the initial contact area for the stationary struck vehicle case. The effect of the 30 MPH tangential velocity was to extend the damage rearward as a result of the sliding action. Structural integrity was better maintained for the latter case as evidenced by the penetration of the front door sheet metal by the bumper and fender of the striking vehicle occurring in Test No. 3 (Figure 28a). Similar to the perpendicular impact situation, the front dummy acceleration exposure was generally more severe for the [illegible] case where the struck vehicle was initially stationary whereas the [illegible]

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* 60° angle between the longitudinal axes of the striking and struck vehicles at impact.

(a) ZERO TANGENTIAL VELOCITY (TEST NO. 1)

(b) 30 MPH TANGENTIAL VELOCITY (TEST NO. 2)

Figure 27 EFFECT OF TANGENTIAL VELOCITY ON VEHICLE DEFORMATION IN 30 MPH PERPENDICULAR COLLISIONS

(a) ZERO TANGENTIAL VELOCITY (TEST NO. 3)

(b) 30 MPH TANGENTIAL VELOCITY (TEST NO. 4)

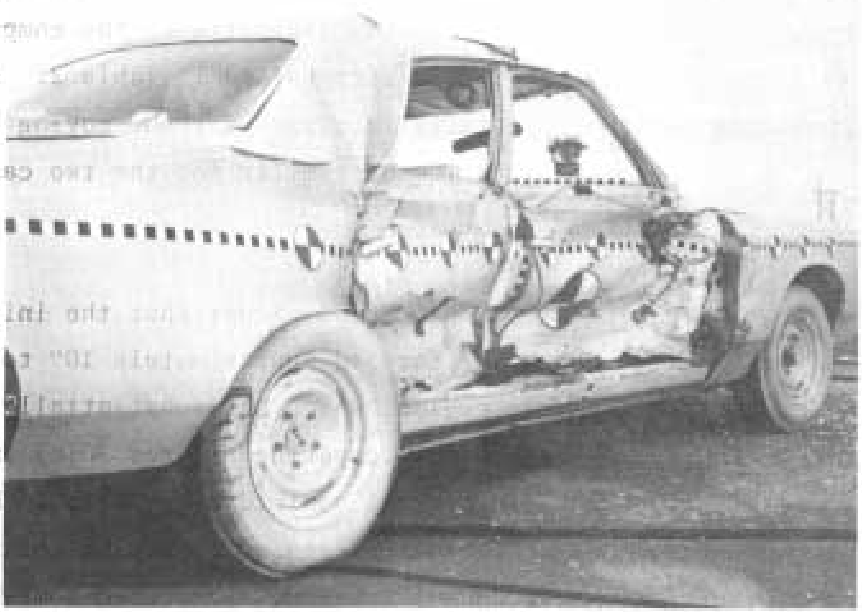
Figure 28 EFFECT OF TANGENTIAL VELOCITY ON VEHICLE DEFORMATION IN 30 MPH OBLIQUE COLLISIONS acceleration response was generally higher for the 30 MPH tangential velocity case (see Table 3).

Test No 5 was similar to Test No. 1 except that the striking vehicle impact velocity was increased from 29.7 MPH to 37.3 MPH. Figure 29 compares the struck vehicle damage and indicates that the increased impact speed produced substantial override of the floorpan sill structure and sheared the B-pillar from the sill attachment point. The increase in static intrusion and average lateral acceleration of the struck vehicle is evident when referring to Table 2. Front and rear dummy lateral accelerations were significantly increased for the higher speed case to the point where the front dummy acceleration exposure appears to be marginally survivable and the rear dummy chest response clearly exceeded the assumed human tolerance limits (see Table 3).

Test No. 6 corresponded to the same oblique impact configuration as Test No 3 except that a contoured-face moving barrier was substituted for the conventional striking vehicle Comparing Figure 30(a) and Figure 28(a), it is clear that the moving barrier resulted in a more evenly distributed loading than the conventional striking vehicle The magnitude of impact loading was approximately double for the moving barrier case as indicated by the comparison of struck vehicle lateral acceleration levels contained in Table 2 Front dummy lateral accelerations were substantially increased for the moving barrier case, whereas the rear dummy responses were quite similar for the two cases (see Table 3).

Test No. 7 was similar to Test No 4 except that the initial contact point on the struck vehicle was moved forward approximately 10" to determine the effect of loading the A-pillar region, which has substantially more lateral strength than the front door structure Comparing Figures 30(b) and 28(b) indicates very little difference in overall vehicle deformation. However, intrusion of the front door structure was increased by moving the impact point forward and, conversely, the rear door intrusion was reduced somewhat (see Table 2). Correspondingly, the lateral acceleration response of the front

(a) TEST NO. 1 (29.7 MPH)



(b) TEST NO. 5 (37.3 MPH)

Figure 29 EFFECT OF IMPACT SPEED ON STRUCK VEHICLE DEFORMATION FOR PERPENDICULAR LATERAL COLLISIONS

(a) TEST NO. 6 (MOVING BARRIER)

(b) TEST NO. 7 (IMPACT POINT MOVED FORWARD)

Figure 30 EFFECTS OF MOVING BARRIER IMPACT AND OF MOVING THE IMPACT POINT FORWARD dummy was significantly more severe for the case where the impact point was moved forward, whereas the rear dummy loading was significantly reduced

Considering the series of baseline tests as a whole, the side structures of the struck vehicles were generally quite effective in maintaining structural integrity, i e , preventing catastrophic sidewall collapse and massive intrusion Events that could be categorized as structural failures were limited to the sheet metal penetration that occurred in Test No 3 (which could have produced lower extremity injury) and the shearing of the lower B-pillar structure from the floorpan sill that occurred in Test No 5 However, these structural failures could more reasonably be attributed to the high bumper strength of the striking vehicles

Fracture of the monolithic tempered glass side windows occurred in most instances The fractures were invariably caused by structural deformation of the door structures and/or impact shock, not by dummy contact Although the loss of side glazing provided a possible route for front occupant partial ejection under the particular test conditions examined, complete containment of the dummies was maintained in all cases The nature of the contact between the intruding door structure and the front dummy tends to prevent motion of the dummy's head through the front door window opening by thrusting the torso away from the struck side of the vehicle before large lateral flexion of the neck takes place.

TR-VR2

The mechanics of the dummy/sidewall collision are such that the dummy tends to remain fixed with respect to the pre-impact vehicle geometry until contact by the intruding side structure takes place Consequently, it is reasonable to assume that the severity of the dummy response is related to the relative lateral velocity between the dummy and the intruding structure at the time of contact The following table provides some insight into the nature of the front dummy/sidewall contact dynamics

BARZELINE ONLY

Test No.	Peak Chest Lateral Acc. (g)	Time of Dummy Contact (msec.)	V_{pc} (MPH)	V_{fd} (MPH)
1	35	25	3.2	16.0
2	28	30	3.0	9.6
3	42	60	3.4	15.6
4	26	35	1.4	5.0
5	46	25	3.2	17.8
6	63	40	4.7	21.0
7	61	50	1.7	14 2

where

V_{pc} is the lateral velocity of the passenger compartment at the time of dummy contact (determined from output of an accelerometer fixed to the forward floorpan structure)

and V_{fd} is the lateral velocity of the front door inner panel at the time of dummy contact (determined from output of an accelerometer fixed to the door panel). Since the front dummy has no appreciable motion prior to contact, this is essentially a measure of the relative velocity between the dummy and the intruding door structure.

These results demonstrate that the door structure in all cases was accelerated to a lateral velocity (V_{fd}) at the time of dummy contact that greatly exceeded the lateral velocity of the overall passenger compartment (V_{pc}) occurring at the same point in time. This points out that the kinematic response of an undeformed part of the passenger compartment does not meaningfully indicate the severity of occupant-to-sidewall contact, i.e., the relative lateral velocity between an occupant and the adjacent (intruding) sidewall must be considered. Figure 31 shows that the severity of the resulting dummy chest acceleration generally increased as the relative velocity between the dummy and the intruding door increased. Indeed, with the exception of the data point for Test No. 7, a strong parabolic relationship is suggested. Figure 31 essentially characterizes the limit of protection provided by the conventional inner door panel, which possesses no substantial energy absorption or load-limiting capability since the stiff metal door panel is covered only by a very thin (about 3/16" thick) layer of upholstery material.

EMPHASIS ON CONVENTIONAL

6.2 Modified Vehicle Tests

Lateral impact tests of modified vehicles were performed under the test conditions that resulted in the generally more severe injury exposure for the front seat occupants (Part 572 dummies), based on the baseline test results. These were the higher speed perpendicular impact condition (Configuration No. 7) and the oblique impact configuration wherein the struck vehicle was assumed to be initially stationary (Configuration No. 3). Modified vehicle test results are presented in Section 5 and Appendix B. In the following sections, results of the perpendicular and oblique impact tests are discussed separately, and a general evaluation of the overall test series is presented.

6.2.1 Perpendicular Impact Condition

The discussion of the baseline test results in Section 6.1 suggested that the severity of occupant acceleration response is directly related to the relative lateral velocity between the occupant and the vehicle interior side wall at the time of initial contact. This appears to be correct because the major acceleration of the sidewall tends to take place before occupant contact occurs.* It follows that the relative lateral velocity should be minimized in order to improve occupant survivability. Two approaches (and a combination of the two) were investigated in the modified vehicle test series.

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* This assumes an initial spacing between the occupant and the adjacent sidewall corresponding to the nominal seating position selected for the crash tests (see Section 2.3).

WHY NO CHART LIKE
THIS ON MODIFIED TESTS

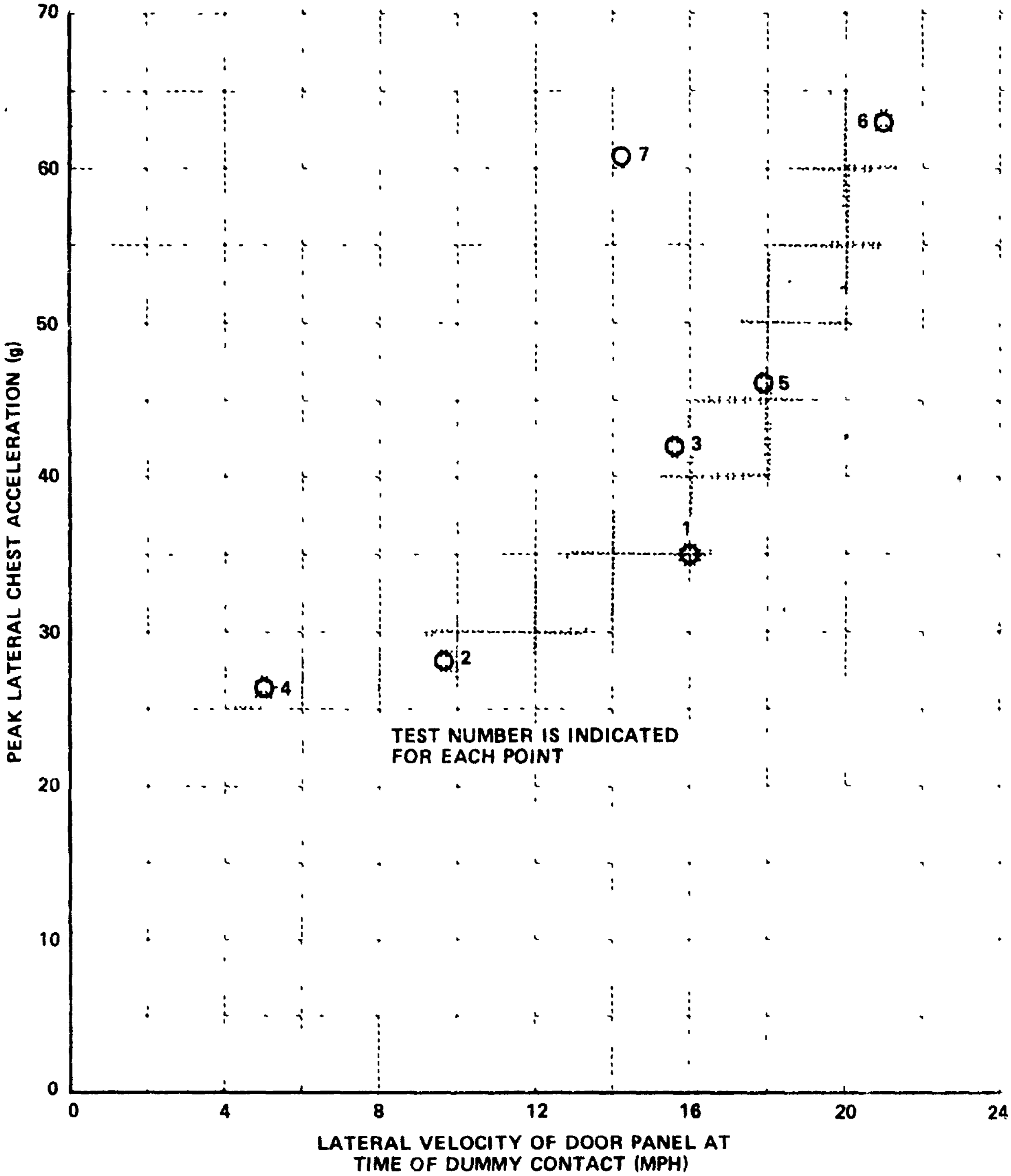

Figure 31 RELATIONSHIP BETWEEN RELATIVE CONTACT VELOCITY AND DUMMY RESPONSE

(a) Structural Modification

This approach was directed towards reducing the magnitude of compartment intrusion and, more importantly, the intrusion velocity. (The lateral sidewall velocity is the summation of the local intrusion velocity and the overall vehicle lateral velocity.) This approach has its limits due to the physical law of conservation of momentum which dictates the magnitude of the overall vehicle lateral velocity change.

(b) Interior Padding

Application of crushable or yielding materials to the interior sidewall can provide a means of controlling (limiting) occupant loading after initial contact up to the point where a common lateral velocity is achieved (when the relative velocity between the occupant and the sidewall behind the padding becomes zero and rebound commences). This approach also has its limits because of dimensional (material thickness) constraints and the need to maximize energy absorption while maintaining tolerable occupant loading. Exhaustion of energy absorption capability results in the material "bottoming out" against the sidewall structure.

(c) Combination of Structural and Interior Modifications

Combination of both the above approaches in an effective manner would appear to provide maximum occupant protection in lateral collisions by improving structural integrity and controlling occupant loading.

Comparing results of the following perpendicular lateral impact tests enables an evaluation of these approaches for improving occupant protection since all four combinations of structural and interior configurations are represented.

Test No	Impact Velocity (MPH)	Modifications
5 (b.l.)	37.3	None
8	39.1	Structural only
N-1	39.2	Interior only
9	39.1	Structural and Interior
12	50.5	Structural and Interior

An exhaustive study of these test results is beyond the scope of this discussion and, therefore, emphasis will be placed on the front dummy/front door interaction mechanics.

Figure 32 compares the resultant chest acceleration responses* for the four cases corresponding to a nominal impact velocity of 37 to 39 MPH. It is immediately apparent that the interior modifications had a more pronounced effect on the control of acceleration response than the structural modifications. That is, the acceleration responses for Test No. 5 (baseline) and Test No. 8 (modified structure only) are very similar, whereas the interior modifications employed in Tests No. 9 and N-1 more effectively increased the duration and limited the magnitude of the acceleration waveform.

Based on a 3 msec. clip criterion, the peak lateral acceleration for the modified structure case (Test No. 8) exceeded the baseline (Test No. 5) response (73 g's vs 46 g's). Explanation of this can be based on the difference in impact velocities, which apparently resulted in a greater maximum

* Filtered according to SAE J211, Class 180 specifications.

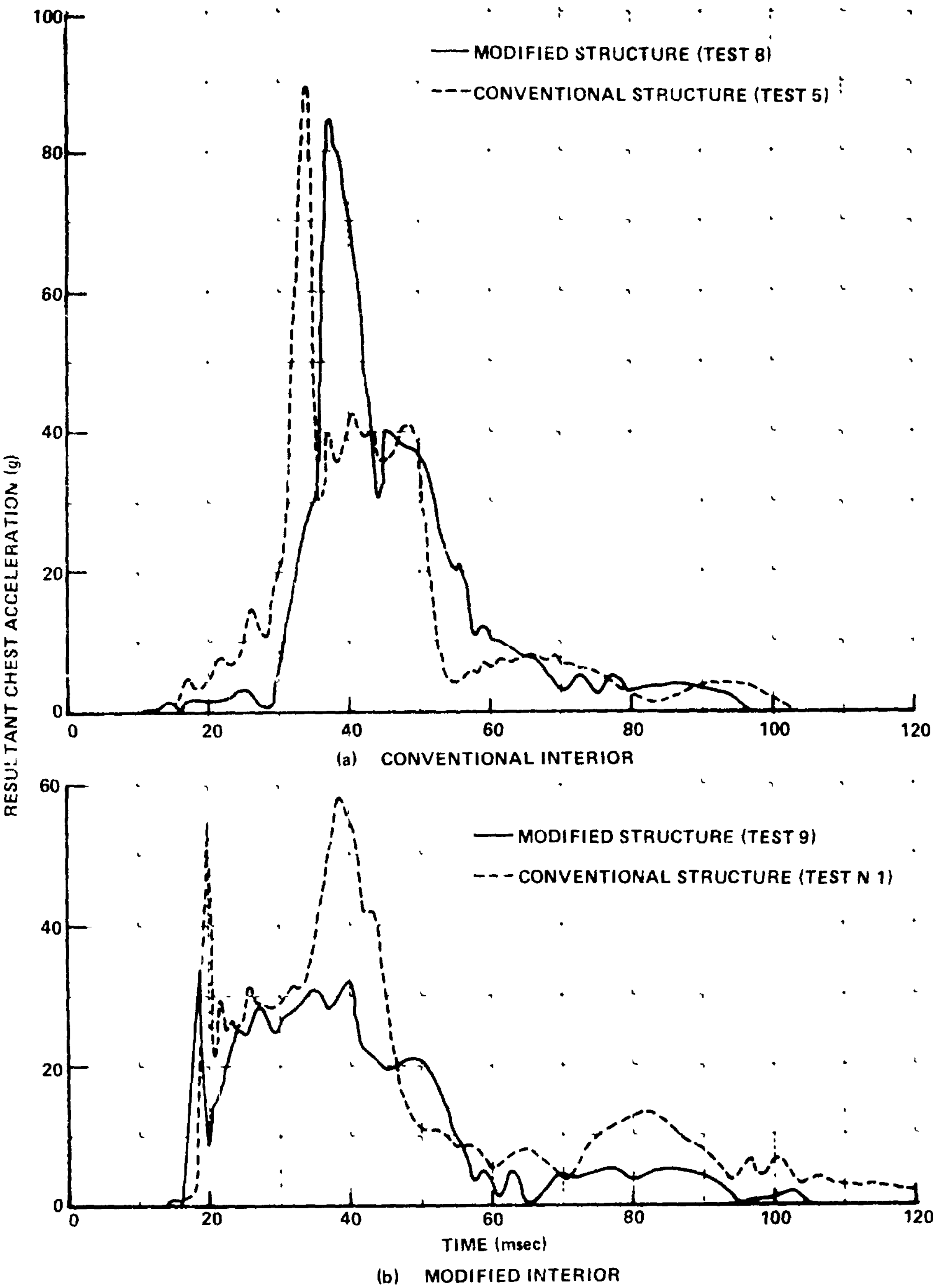

Figure 32 EFFECT OF STRUCTURE AND INTERIOR ON FRONT DUMMY RESPONSE IN PERPENDICULAR COLLISIONS

relative velocity between the dummy and the sidewall for the modified structure case (20.5 MPH vs. 17.8 MPH).* Results indicate that the front door intrusion velocity (as well as displacement) was actually reduced somewhat by the structural modifications, but the increased lateral acceleration (and associated velocity change) of the overall vehicle early in the collision impulse prevented reduction of the relative velocity between the dummy and the intruding inner door panel.

It is clear that the most effective control of front occupant acceleration response was obtained for the case of combined structural and interior modifications (Test No. 9). For the case of interior modification only (Test No. N-1), the crushable door panel padding bottomed out at approximately 35 msec. (see Figure 32b), which was followed by the relatively high acceleration pulse between 35 and 45 msec. The higher velocity change of the dummy for this case as compared with that of Test No. 9 (compare areas under acceleration curves) suggests that the conventional side structure was considerably less effective than the modified structure in limiting the relative lateral velocity between the dummy and the intruding door panel.

Figure 33 provides further insight into the dummy/door panel interaction for Test No N-1 The high bottoming loads that resulted in this instance are believed to be rather unusual because the crushable door panel successfully accelerated the dummy to a velocity common to that of the door panel behind the padding (zero relative lateral velocity) without applying excessive torso loading. However, at the instant that bottoming occurred, the door panel sustained a high acceleration pulse to which the dummy was also subjected. If these events had not occurred simultaneously, the performance of the crushable padding would probably have been more impressively demonstrated.

* Note that the point x = 20.5 MPH, y = 73 g's is consistent with the envelope of data points in Figure 31 that characterizes the conventional interior door panel stiffness

Test No. 12 illustrates the case where quite adequate compartment integrity was maintained by the structural modifications,* but the high impact severity (50 5 MPH) and associated high lateral velocity change clearly exceeded the energy absorption capacity of the crushable door panels. Figure 34 shows that at the point when the padding bottomed out (32 msec), the relative lateral velocity between the door panel and the dummy was on the order of 15 MPH. Door panel accelerations following the time of bottoming were relatively low, unlike the previous case illustrated (see Figure 33) Therefore, in this instance, the high acceleration response resulted from the residual relative velocity at the time of bottoming and not from transmission of structural acceleration to the occupant (commonly referred to as vehicle "ride-down")

6 2.2 Oblique Impact Condition

The general discussion of structural and interior modifications contained in Section 6.2.1 applies equally to the oblique impact condition. For this case, the modified vehicle tests provide the following comparisons of structural and interior performance

Test No	Impact Velocity (MPH)	Modifications
5 (baseline)	29.7	None
10	29.8	Structural Only
6 (baseline)**	29 6	None
11**	30.2	Structural and Interior

Figure 35 presents a comparison of the front dummy resultant chest responses for these four cases.*** For the case of structural modification

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* The structural deformations and passenger compartment static intrusion were generally comparable to results of the 37 3 MPH baseline condition (Test No 5)

** Contoured face moving barrier impacts

*** Filtered according to SAE J211, Class 180 specifications

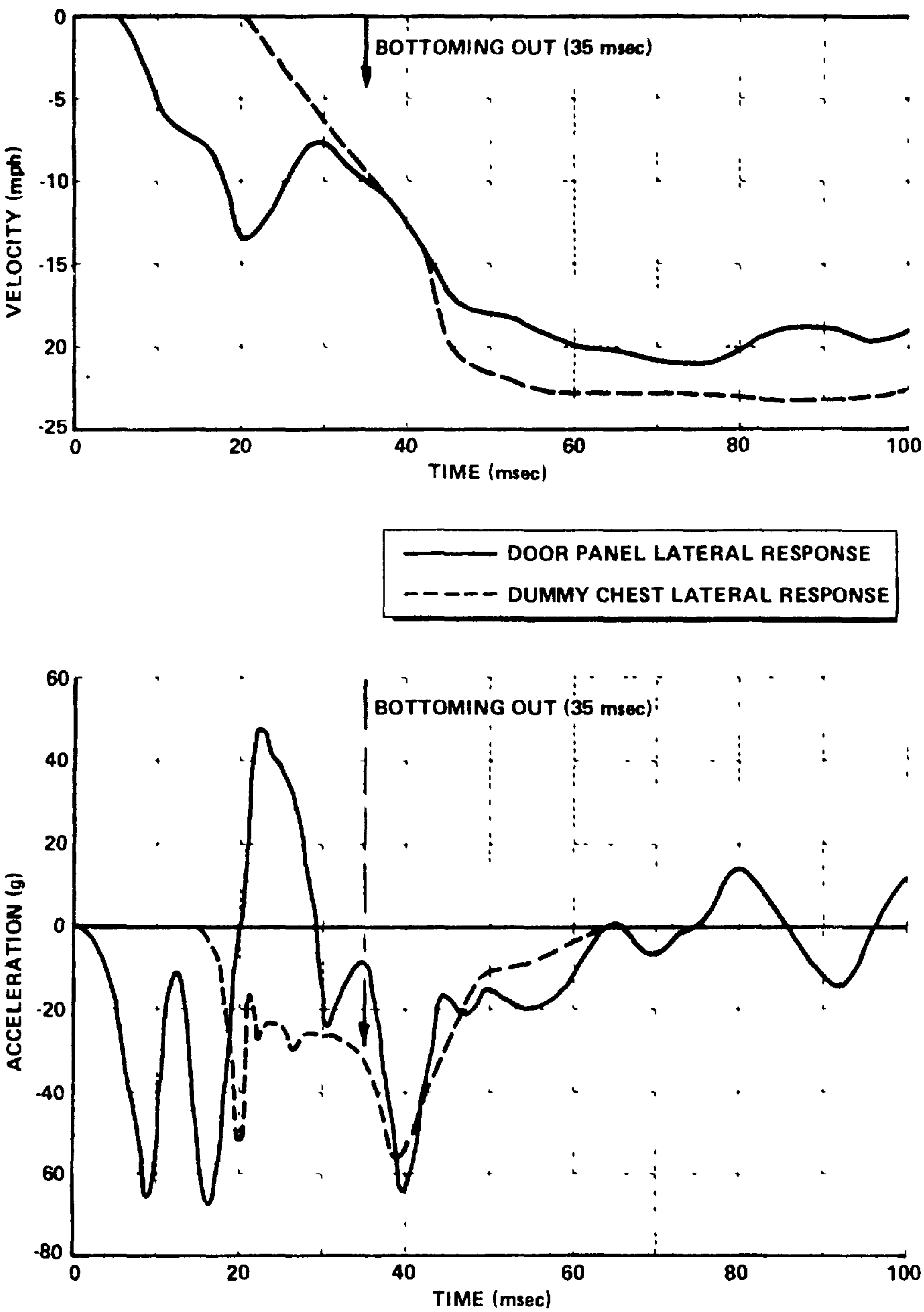

Figure 33 DYNAMIC RELATIONSHIP BETWEEN DOOR PANEL AND FRONT DUMMY FOR TEST NO. N-1

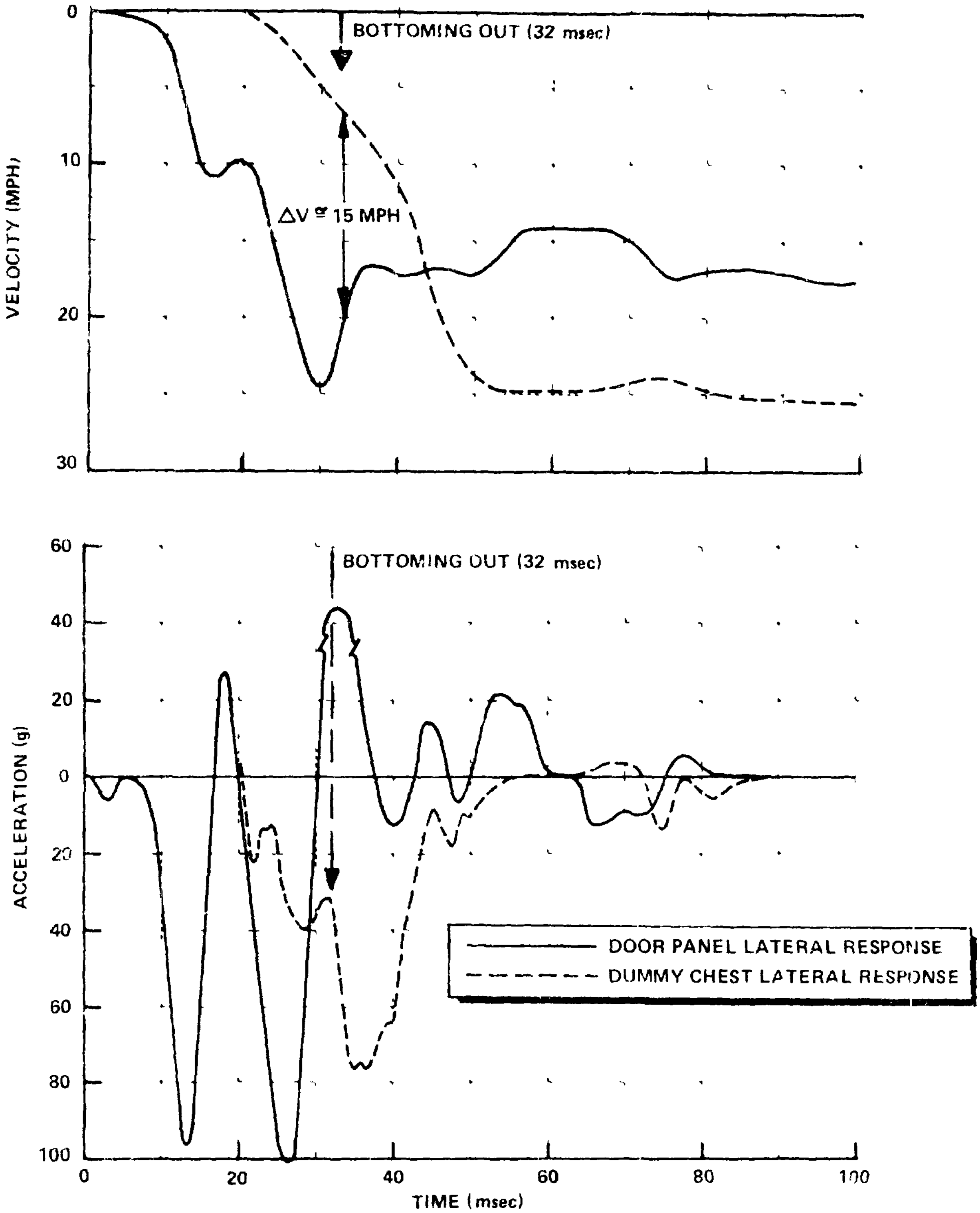

Figure 34 DYNAMIC RELATIONSHIP BETWEEN DOOR PANEL AND FRONT DUMMY FOR TEST NO 12

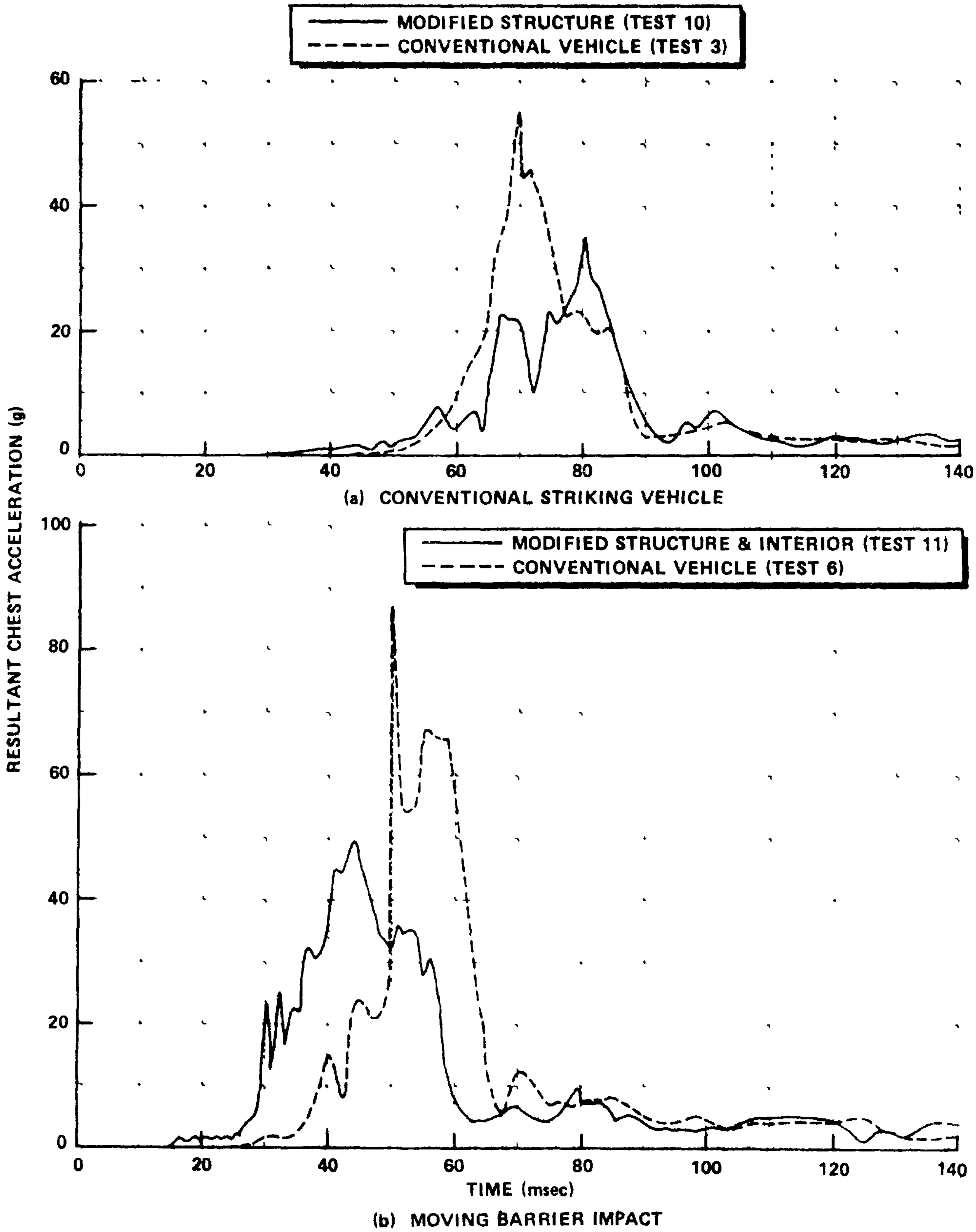

Figure 35 EFFECT OF STRUCTURE AND INTERIOR ON FRONT DUMMY RESPONSE IN OBLIQUE LATERAL COLLISIONS

only (Figure 35a), the characteristic waveshape was generally maintained except that the peak lateral acceleration was reduced substantially (from approximately 42 g's to 30 g's, based on a 3 msec clip criterion). Since the impact velocities were nearly equal, it appears that this improvement resulted from the reduction of the maximum relative velocity between the dummy and the adjacent door panel structure. Test data substantiate this conclusion since the maximum relative lateral velocity was reduced from approximately 15.6 MPH for the baseline condition to about 11.3 MPH for the structurally modified vehicle case.*

The application of structural and interior modifications for the moving barrier impact condition clearly influenced the nature of the dummy responses in that the chest loads were effectively limited and increased in duration by the crushable door panel. This resulted even though the maximum relative lateral velocity between the dummy and the door structure (behind the padding) was not substantially changed by the structural modifications (18.9 MPH vs. 21.0 MPH for the baseline condition). Peak lateral acceleration of the front dummy was reduced from 63 g's to 44 g's principally due to the interior modifications.

6.3 General Discussion

The preceding evaluation of the baseline lateral impact performance, although limited in scope, clearly indicated that the severity of occupant injury exposure is related to the relative velocity between the occupant and the contacted sidewall surface, since the conventional vehicle interior possesses inadequate load-limiting or yielding properties. Structural modifications, although somewhat effective in reducing the relative contact velocity, appear to be fundamentally limited as to the extent of occupant protection that can be

* Note that the point x = 11.3 MPH, y = 30 g's falls within the envelope of data points in Figure 31.

gained without the associated application of protective interior surfaces.*
It should be pointed out, however, that structural modifications which resist massive sidewall collapse in lateral collisions more severe than considered in this study would very likely enhance the survivability of occupants seated away from the impacted side of the vehicle

The crushable door panel installations were shown to be quite effective in controlling occupant loading However, further refinement of the crush strength (load-deflection) properties is needed to demonstrate further occupant protection. Figure 36 illustrates the extent of crush at the upper torso contact area that resulted for the front door panel installations corresponding to the particular crash tests. Complete crush of the upper torso contact area occurred in all cases except for Test No. 9 (complete structural and interior modifications), in which approximately 1" of uncrushed depth remained. Crush capability of the lower contact areas from lower torso and hip impact appeared to have been exhausted in all cases. Evaluation of the torso response waveshapes and the physical crush evidence indicates that the paper honeycomb crush strength needs to be increased by about 25%. This could be accomplished by either reducing the cell sizes or impregnating the paper with phenolic resins.**

Inspection of Tables 3 and 10 indicates that unacceptably high head loading did not occur under any of the baseline or modified vehicle test conditions, based on the assumed HIC limit For the front dummy case, impact with the roof header and/or glazing surface was either prevented or minimized (low contact velocities) by the nature of the lateral occupant kinematics. Rear occupant contact with the upper C-pillar area appeared to be marginally tolerable in some of the cases, but the installation of the urethane padding material effectively controlled head loading

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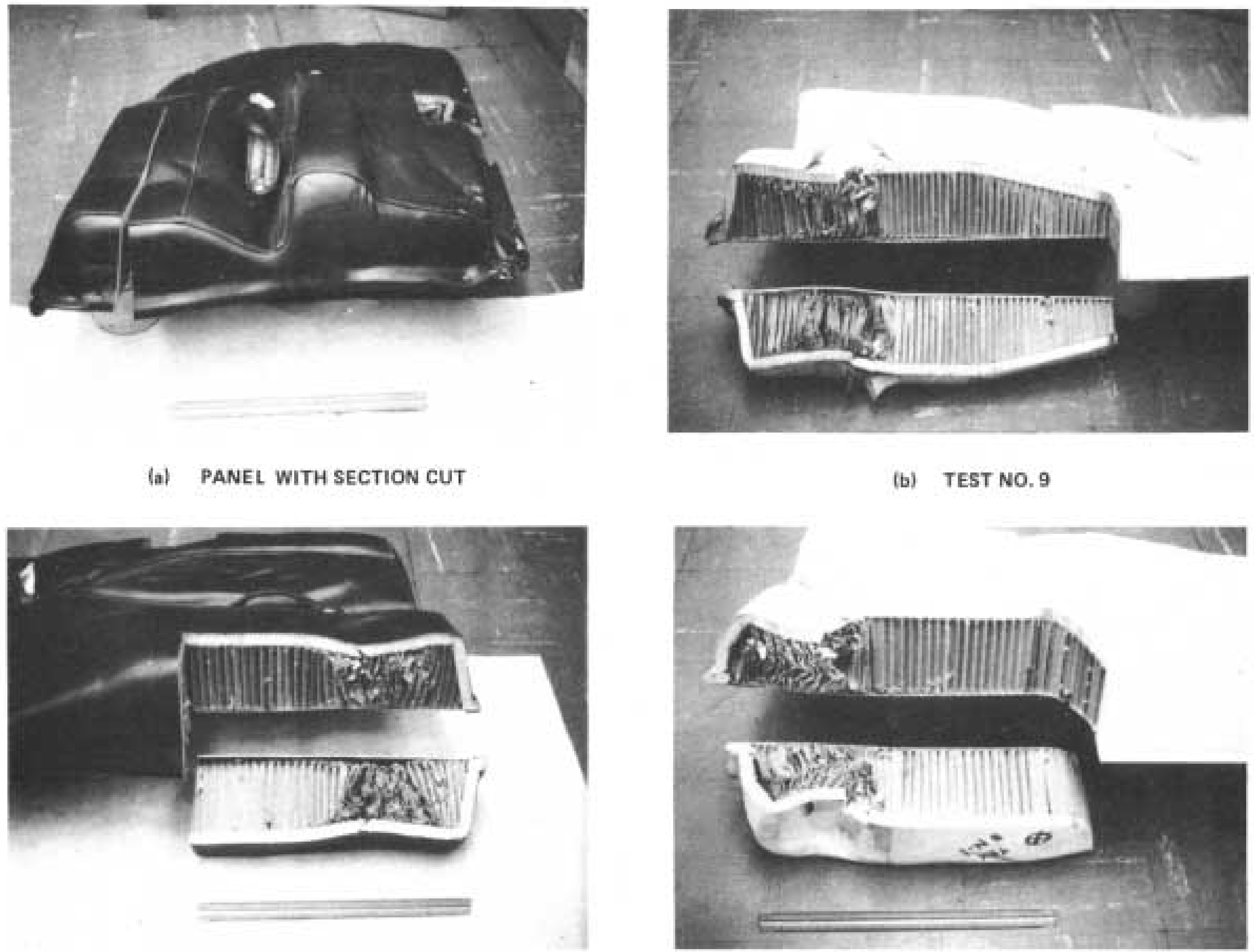
* This is analogous to the frontal impact protection problem in that an effective restraint system is absolutely necessary to take advantage of structural crashworthiness improvements.

** As discussed in Section 4.3.2, impregnation would likely be required for humidity and moisture absorption protection.



(a) PANEL WITH SECTION CUT

(b) TEST NO. 9

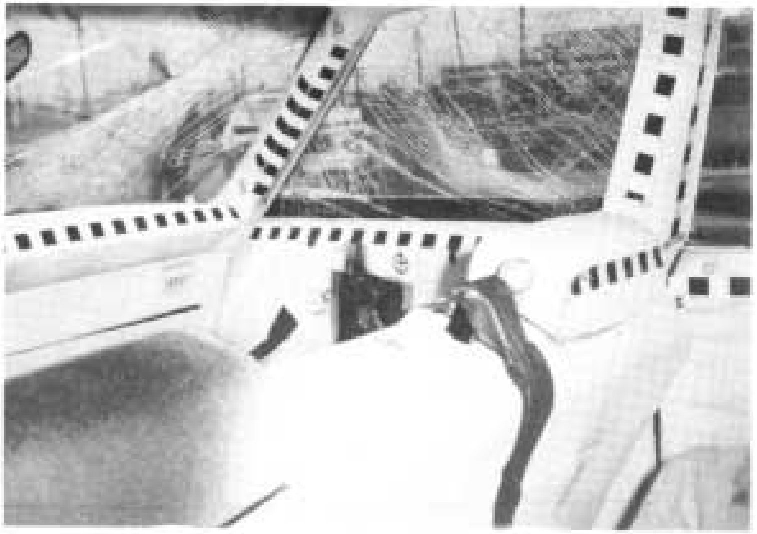
(c) TEST NO. 11

(d) TEST NO. N-1

Figure 36 ILLUSTRATION OF DOOR PANEL HONEYCOMB CRUSH

With respect to the laminated glazing installations in the modified vehicles, there was no indication of significant head contact resulting from the lateral impact tests. Consequently, although the peripherally supported glazing provided an energy-absorbing containment surface as shown in Figure 37, no such additional protection appeared to be needed, at least for the particular impact conditions considered Fracture of the glass plies evident in Figure 37 was caused by the structural impact response in all cases and not by dummy contact. Such a containment surface would more likely be of benefit in rollover accident types, particularly if occupants are unrestrained The need for protective side glazing could also be more apparent in other lateral impact modes and/or for automobiles of smaller size (see Ref 4) Finally, the degree of anthropomorphic dummy lateral response fidelity has an important bearing on this subject *

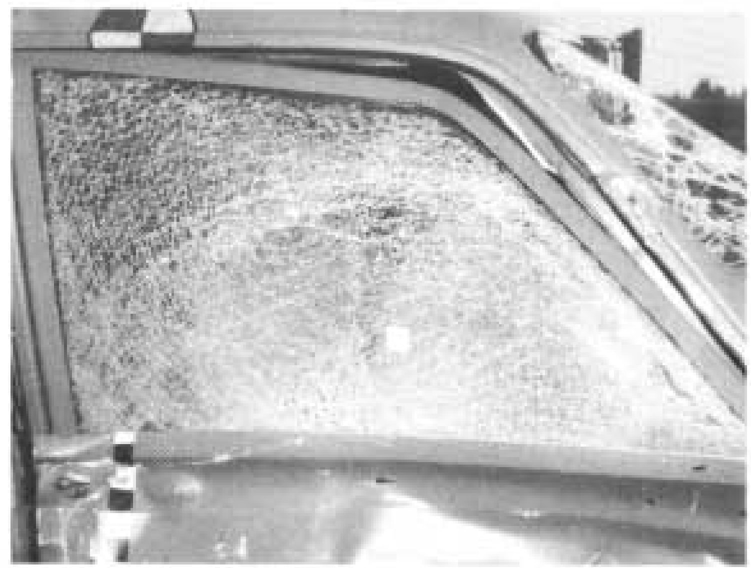
* The degree of lateral impact fidelity of test dummies has not yet been established. It is probable that dummies of different make and model possess different lateral impact response characteristics, but more research is needed to firmly establish the nature and significance of this probable variability. NHTSA is cognizant of this need as evidenced by the issuance of RFP No. NHTSA-6-A202, "Calibration Procedures of Test Dummies for Side Impact Testing," August 15, 1975.



(a) TWO-PLY ANNEALED (TEST 8)

(b) TWO-PLY ANNEALED (TEST 10)

(c) TWO-PLY ANNEALED (TEST N-1)



(d) BILAYER (TEST 12)

Figure 37 EXAMPLES OF LAMINATED GLAZING FRACTURE

7. CONCLUSIONS AND RECOMMENDATIONS

The following specific conclusions and recommendations are based on the results of this study.

- Test Methodology

The procedure developed for performing lateral impact crash tests where forward motion of both the striking and struck vehicles is simulated (see Section 2.1) has been found to be reasonable to perform, easily repeatable and realistic. Collision mechanics and primary occupant responses are believed to be validly represented by transferring the assumed initial velocity vector of the struck vehicle (in the reversed direction) to the striking vehicle However, post-impact vehicle trajectories and secondary occupant responses are not well simulated due to the unrealistic tire/ground interface forces which control the vehicle kinematics following the collision impulse Nevertheless, the method is well suited to the study of primary impact dynamics, which was the focus of this study.

Application of laterally-oriented accelerometers to the impacted interior sidewall of the struck vehicle has been found to provide important information relative to the study of occupant/interior collision interaction Accelerometers placed at undeformed vehicle locations, as has been standard practice, are needed to provide data which characterize the overall vehicle dynamic response

- Conventional Vehicle Crashworthiness

The side structure of the conventional, full-size automobile investigated generally performed effectively in maintaining structural integrity and preventing massive compartment intrusion under the lateral impact conditions considered (see Sections 3 and 6.1). For perpendicular lateral collisions, substantial override of the floorpan side sill and failure of the lower

B-pillar attachment can be expected to occur for impact velocities exceeding about 35 MPH. However, this would not be expected to result in totally unacceptable collapse of the side structure unless the impact speed substantially exceeded the 35 to 40 MPH range. For the case of oblique lateral impact, 30 MPH structural performance appeared to have been adequate with the possible exception of a tendency to penetrate the lower structure by the bumper structure of a striking vehicle. A moving barrier impact condition produced somewhat greater intrusion of the passenger compartment at the vehicle belt line (mid-level) that approached an excessive magnitude at 30 MPH.

Not necessarily true

With respect to occupant protection provided by the interior passenger compartment sidewall surfaces, it was shown that the magnitude of acceleration response of an occupant seated adjacent to the impacted sidewall is directly ~~related~~ to the relative velocity between the occupant and the intruding structure at the time of contact. Since major sidewall acceleration tends to occur prior to such contact, relative velocities exceeding approximately 14 to 18 MPH generally resulted in peak lateral chest accelerations that exceeded the assumed human tolerance limit of 45 g's.

The conventional monolithic tempered side glazing fractured in most instances as a result of structural deformation of the door structure under the impact condition investigated. Although this provides a possible route for occupant ejection (at least partial ejection of parts of the upper body), complete containment of occupants (Part 572 dummies) within the passenger compartment outer surfaces was maintained in all cases.

It is concluded that the most significant deficiency of the conventional vehicle design relating to lateral collision occupant protection is the general lack of energy absorbing or yielding (load-limiting) interior side surfaces. For the particular automobile considered, the primary areas of concern are the front and rear door inner panels and the region of the C pillar structure (behind the rear door adjacent to a rear seated occupant).

- Alternative Glazing Materials and Constructions

Results of headform impact testing of peripherally supported, laminated glazing specimens demonstrated that a two-ply annealed glass construction utilizing a .030" PVB interlayer would provide adequate head impact protection and containment for head-to-glass impact velocities up to at least 20 MPH. Since this type of glazing is currently employed for all domestic automobile windshields and was at one time (prior to the late 1950's) used for side windows, production feasibility is not in doubt. However, return to laminated annealed glass sidelites would (1) increase production costs substantially, (2) increase the replacement rate because of the fragileness of annealed glass (susceptible to breakage from door slamming) and (3) probably increase laceration injuries in lateral collisions due to its hazardous fracture properties.

Two ply thermal tempered glass with a PVB interlayer would not possess the above stated deficiencies of laminated annealed glass except for a similar, if not higher, production cost increase relative to present monolithic tempered glass sidelite cost. However, as a result of warpage problems during thermal tempering, there is a limiting thickness at which tempered glass can be employed in a laminated construction (estimated to be about 5/32" with present day production techniques). Headform impact test results indicated that a two-ply construction of 5/32" tempered glass possesses a dynamic breakage strength that would produce excessive head loading at head-to-glass impact velocities exceeding about 10 MPH (assuming that the glass plies are not fractured prior to head contact by structural deformation or other causes).

The most attractive alternative to monolithic tempered glass, at least from a head protection and containment surface standpoint, appears to be a two-ply, exposed plastic construction in which tempered glass is employed as the outside layer and the inside layer is composed of a thin plastic material. The advantages of such a "bilayer" construction are (1) no significant weight increase over conventional monolithic tempered glass, (2) improved energy-absorption and containment properties if the laminate is effectively supported and (3) reduction or elimination of laceration potential due to the protective plastic inside layer. Inherent disadvantages are (1) increased production cost, (2) questionable durability because the abrasion resistance of the inside (plastic) surface would be inferior to glass and (3) questionable resistance of the plastic material to prolonged humidity and moisture exposure, various chemicals and to other possible deteriorative environmental conditions

With respect to the possible durability deficiencies of exposed plastic laminates, it is well known that this type of glazing construction in its present state of development, will not meet the requirements of FMVSS No 205 for motor vehicle use in areas requesite for driver visibility The primary and possibly insurmountable obstacle preventing conformance with FMVSS No. 205 is the inability of known plastic materials to meet the specific abrasion resistance test requirement, which was based on glass abrasion properties In view of the potential advantages of exposed plastic laminates, particularly for windshield application, it is recommended that the FMVSS No 205 requirements be reviewed to ascertain whether or not relaxation of the abrasion test condition is possible for the inside glazing surface without compromising the essential need for durability and optical acceptability throughout a reasonable service life of an automobile. If suitable relaxation of the specific safety standard is feasible, development of exposed plastic laminate for automotive application by glass manufacturers will not be inhibited or precluded

Finally, results of this investigation have demonstrated that it is possible to provide adequate peripheral support to laminated side glass through suitable design of an upper door frame and peripheral frame bonded to the glass edge, while preserving normal side window rolldown operation.

• Interior Padding Materials and Constructions

Results of static and dynamic tests of crushable paper honeycomb materials using a lateral body form show that these materials possess excellent energy absorption and load-limiting properties (see Section 4 3). Proper selection of cell size (or a combination of materials with different cell size) allows a door panel to be constructed that uniformly distributes loading of an occupant resulting from a lateral impact. The paper honeycomb can be shaped to provide an inner surface incorporating an armrest and other needed contours, a resilient material can also be used to cover the honeycomb for resisting damage during normal vehicle usage and from impacts of relatively low speed.

It remains to be demonstrated that paper honeycomb is a viable material for automotive application. The principal concerns are (1) reduction of crush strength as a result of prolonged high humidity exposure, (2) deterioration of the paper resulting from moisture absorption, and (3) flammability. It is possible that these deficiencies can be overcome by impregnation with phenolic resins and application of flame-retardant chemicals. However, more research is needed to resolve the feasibility question.

An experimental expended urethane material was also examined which exhibits exceptional energy absorption capability and recoverability. This material, which is highly viscoelastic, appears to be well suited for head impact protection. As is the case with urethanes commonly used in energy-absorbing dashpanels, the material properties are sensitive to temperature, i.e , stiffening occurs at low temperatures and high temperature produces softening. However, normal compartment heating and cooling would be expected to alleviate this problem. Flammability, toxicity and production costs remain to be evaluated.

In view of the fact that protective interior side surfaces are virtually non-existant in present-day automobiles, it is concluded that extensive further research is needed to establish the feasibility of utilizing energy absorbing materials for improving lateral impact protection.

- Modified Vehicle Crashworthiness

The structural modifications incorporated in the struck vehicles demonstrated substantial reduction in side structure deformation and passenger compartment intrusion. Structural performance under a perpendicular lateral impact condition at approximately 50 MPH was generally comparable to the conventional vehicle structural performance at about 40 MPH, indicating a nominal increase in kinetic energy dissipation capability on the order of 50 to 60%. However, it has been found that structural modification in itself is fundamentally limited as to the extent of occupant protection that can be provided. This appears to be the case because the acceleration response of an occupant (Part 572 dummy) was shown to relate directly to the relative velocity between the occupant and the adjacent interior sidewall at the time of contact. For similar initial dummy positions, structural modifications were shown to reduce the relative contact velocity somewhat but conservation of linear momentum considerations prevent substantial reduction. Structural modifications also appear to be more beneficial in oblique lateral collisions than in perpendicular impact modes. Furthermore, it is concluded that occupants seated away from the impacted side would most benefit from structural modification in extremely severe lateral collisions.

Modification of the vehicle interior side surfaces to directly control occupant loading is the most effective approach for improving occupant protection, particularly when combined with structural modifications. Although further refinement in the yielding surface characteristics is needed, the interior protective surfaces investigated in this study (crushable door panels and compressible padding) clearly exhibited effective energy management and load-limiting properties. It is concluded that emphasis should be placed on improving the interior protection provided by automobiles. In our judgment such improvement is clearly needed and would probably provide the greatest payoff related to enhancing occupant survivability in lateral collisions.

Peripherally supported, laminated side glazing has been shown to provide an effective containment surface, such protection against partial ejection in lateral collisions is not provided by conventional monolithic tempered glass side windows However, the lateral impact test conditions considered in this study did not result in significant occupant contact with the laminated side glazing, which indicates that no direct benefit was demonstrated. Consequently, results of this investigation do not convincingly support a recommendation for side glazing modification This is not to say, however, that such side glazing changes would be unbeneficial in other lateral impact modes and, most importantly, in rollover accidents where unrestrained occupants are most susceptible to ejection. In this regard, it is suggested that a restraint system that is effective in lateral and rollover collisions (minimally, a lap belt) is the primary element needed for reducing the likelihood of ejection through window openings

- Front/Side Structure Compatibility

Although not specifically addressed in this study, it is clear that the collapse properties of front structures have an important bearing on side structure performance and associated occupant protection in intervehicular lateral collisions Tailoring the force-deflection characteristics of front structures so as to more evenly distribute the energy absorption between striking and struck vehicles would ease the demands placed on side structure performance and also, if the magnitude and rate of sidewall intrusion can be reduced by improving front-to-side compatibility, increase the effectiveness of yielding interior surfaces. Geometric compatibility between front and side structures is of equal importance since the location and distribution of side structure loading directly affects the pattern of structural deformation. It is therefore concluded that increased emphasis should be placed on front structure compatibility in future research related to improving intervehicular lateral collision survivability.

- Anthropomorphic Dummy Fidelity

The results and conclusions of this study are largely based on the lateral response behavior of the Part 572 dummy employed in the crash test program. The realism of this type of test dummy (and others), particularly with respect to lateral collision response, continues to be in question. Although the criticism to this point has been mainly based on subjective grounds, the rigidity of the thoracic spine and the seemingly high flexural and torsional stiffness of the neck raise serious doubts as to acceptable fidelity. It is therefore recommended that a study be conducted to determine the realism of lateral dummy motion and to ascertain the need for further dummy design specifications relating to lateral dynamics.

- Mathematical Modeling of Lateral Collisions

It is recommended that a mathematical model of vehicle/occupant impact dynamics be developed. This appears to be needed to further define the lateral impact injury mechanism and to more intensively study the relative effectiveness of structural (both front and side) and interior modification approaches for improving lateral impact protection.

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